LONGMANS'

TECHNICAL HANDICRAFT SERIES

INCANDESCENT ELECTRIC LAMPS

AND THEIR APPLICATION

DANIEL H. OGLEY

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AND THEIR APPLICATION

BY

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PREFACE

SINCE the advent of the carbon filament incandescent lamp so many wonderful discoveries have been made that the adoption of the electric glow lamp as an illuminant is now almost universal.

A little thought will establish the fact, however, that the improvements made have been chiefly in the lamp itself, the introduction of the metal filament being responsible for the increased efficiency that has placed electric lighting practically within reach of all.

In comparison with the advances made in filament construction those made in the direction of scientific artificial lighting have been small.

The formation of the Illuminating Engineering Society has done much to create an interest in this important subject, while further, the work of Government Commissions and the publication of their reports on school, factory and library lighting has served still more to impress people with the importance of adequate illumination.

If good lighting is important in public institutions it is equally if not more important in the home, and the approved methods of disposing of the light units so as to avoid unnecessary glare and produce an adequate illumination, as well as the judicious selection of wall and ceiling coverings, should be fully understood by all users and installers of electric light.

The existing literature on the subject is of too scientific and technical a character for other than scientists, and in presenting this treatise the author hopes that the obvious gap may be filled and that the general reader may be assisted in deciding upon the most suitable candle-power and distribution in his own particular case.

The author has to thank Messrs. Siemens Bros. for information concerning tantalum and permission to reproduce one of their diagrams; Messrs. The General Electric Co. for information concerning the drawing down of tungsten filaments ; Messrs. The Institution of Electrical Engineers for use of blocks illustrating standard lamps ; the American Illuminating Engineering Society

for permission to use blocks appearing in their Primer ; the editors of the *Electrical Review* and Messrs. The British Thomson-Houston Co.

To the latter company and to their lighting expert, Mr. R. Eastman, his special thanks are due, for without their very generous assistance in the matter of blocks and photographs the publication of this work would have been almost impossible.

The author is indebted to Dr. Rhodes for proof reading and valuable advice, to Mr. W. Hill for assistance with the sketches, and to the publishers for the kind way in which they have assisted in the production of this work.

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CONTENTS

LIST OF ILLUSTRATIONS

TABLES

INCANDESCENT LAMPS

CHAPTER I

THE PRODUCTION AND PROPAGATION OF LIGHT

LIGHT, as far as we are concerned in the present volume, is produced by electrical means, the heating effect of a current being utilised in the production of incandescence, to which phenomenon the light derived from solids generally owes its existence.

It is well known that all conductors of electricity offer obstruction or resistance to the passage of a current through them.

To overcome this resistance energy must be expended, the immediate outcome of the expenditure being an increase in the temperature of the conductor conveying the current, above that of its surroundings.

The actual temperature rise clearly depends upon the construction of the circuit in which the current is maintained.

Thus, if the conductors employed be of ample dimensions, or, what amounts to the same thing, if the current density does not exceed some specified value, the rise in temperature will in general be small.

Electrical machinery of practically every description is designed with a small temperature rise in view, and exacting tests are carried out to ensure that the stated increase is not exceeded.

The production of heat in such cases indicates waste, perished insulation, with the risk of fire often occurring.

On the other hand, however, the conductors may be specially designed of such dimensions and resistance, that luminous radiation capable of producing visual sensations takes place on the passage of a current, or, in other words, the conductors may be heated to such an extent that they become incandescent.

Heating Effect of a Current.—As an example of the application of the above principle, let us consider the case of a thin iron wire conveying current.

The wire will offer resistance to the passage of the current, and to maintain the latter energy will have to be expended.

Provided that the current be of reasonable value, this expenditure of energy will result in a gradual increase in the temperature of the wire above that of its surroundings.

At first the temperature increase will be the only noticeable effect, heat radiation taking place from the wire and producing the sensation of warmth in the hand, if the latter be held in close proximity to the heated conductor.

Eventually, however, on a temperature of approximately 500° C being attained, a change in the colour of the wire will be observed. From its original colour it changes to a dull red, in consequence of which the temperature indicated is known as a dull red heat.

Radiation.—A heated body always tends to equalise its temperature with that of its surroundings by radiation of its energy.

At low temperatures comparatively speaking, the radiation is such as to produce the sensation of warmth only, the amount of the radiation in the visible region being too low to produce in our eyes the sensation of vision.

As the temperature increases, however, a change in the character of the radiation takes place. The proportion of luminous radiation increases, or the body is said to radiate light, and so becomes visible.

The colour of the light emitted at first is dull red, or the radiation is such as to produce visual sensation, first of dull red, then, as the temperature increases, of red, etc., until finally the stage known as that of a white heat is attained.

The temperature of all current-conveying circuits is raised above that of their surroundings, the degree merely depending upon the construction of the particular parts of the circuit.

In the case of the iron wire mentioned above, its temperature must clearly be much higher than that of the copper conductors conveying the current to it, although, obviously, the current in each part of the circuit must be the same.

We see, then, that by placing suitably designed conductors or, as they are more generally termed, filaments, in a circuit, the heating effect of a current can be utilised to raise their temperature to such a degree that they become visible, and in this way the production of light by electrical means is rendered possible.

Incandescent lamps, whether employing a filament of carbon or metal, arethus seen to be merely examples of the application of the heating effect of an electric current, a conversion of energy taking place from an electrical form to that of heat.

Luminous Body.—A body which emits light, or from which light proceeds, is said to be luminous ; distinction being made between those bodies which emit light of themselves, and those which simply reflect light received from some other source.

The former are known as self-luminous bodies, the most conspicuous example being the sun. Incandescent lamps, or rather, the filaments of such, are self-luminous bodies, since they are raised to a high temperature, and so become visible, by the passage through them of an electric current.

The moon is an example of a body that shines by reflected light, in this case the light of the sun, and is not a self-luminous body.

A luminous body radiates light or energy of such a character as to stimulate the eye, and produce in this organ the sensation of vision.

Light itself is simply an expenditure of energy, and its production by electrical means is accompanied by considerable heat-radiation, which latter, from a light-production standard, must always be regarded as waste.

The heat-radiation may readily be detected by holding the hand at some little distance in front of a carbon filament glow-lamp, when the sensation of warmth will be produced, while further, the high temperature attained by the glass bulb will render the touching of the latter a somewhat painful process.

As a matter of fact, the light produced in such cases is merely a bye-product in the production of radiant heat, only 2 per cent. or so of the power supplied to the lamp being radiated as light, the remaining 98 per cent. being practically all wasted in the form of heat.

It is on this account that special types of carbon filament lamps are used as radiators, the light emitted serving no other purpose than to produce a pleasing effect.

With metal filament lamps the power radiated as light is nearly three times as great as in the former case, but even then, 94 per cent. of that supplied is wasted as regards light production.

It will thus be seen that the somewhat circuitous method of producing light by electrical means, is by no means an efficient one, although at the present time it is certainly one of the most convenient methods at our disposal.

Rectilinear Propagation of Light.—A luminous body, such as an incandescent filament, radiates light in all directions, the light always travelling through a homogeneous medium in straight lines.

By a homogeneous medium is meant one that possesses the

same properties at all points, and in all directions, water and air being conspicuous examples.

For the purpose of argument, and to assist in its conception, light may be supposed to travel through a medium such as air along rays, a number of such rays forming what may be termed a beam of light.

The sun is a luminous body, and beams of light produced by it may frequently be noticed. If the sun is shining through a hole in a shutter, or through a break in, say, the roof of a railway station, a conical beam of light will be observed.

Light itself is invisible, but dust-particles in its path reflect the light to the eye of the observer and thus enables the path of the beam to be traced.

The path is seen to be everywhere straight, and such a beam may be supposed to consist of a number of rays, each being a straight line along which the light travels.

Incandescent bodies, such as glowing lamp filaments, behave in just the same manner as the sun. They radiate light in all directions, the light travelling everywhere from the source in straight lines.

Reflection.—When light falls upon a surface some of it is reflected, part absorbed, and the rest transmitted, the proportions depending upon the nature of the surface.

If this latter be of such a kind that practically the whole of the light is reflected, it is called a reflecting surface.

Whenever reflection takes place the light is either reflected according to well-known laws, in which case the reflection is known as regular or direct reflection, or it is scattered, the reflection then being known as diffused reflection.

Regular reflection takes place from the surface of mirrors and polished metals generally, according to the following laws of reflection.

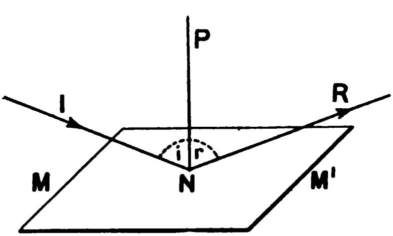

FIG. 1.

Laws of Reflection.—In Fig. 1 let MM′ be a regular reflecting surface such as that of a plane mirror, and further, let I be a ray of light falling upon this surface. Such a ray, actually proceeding from a source, is called an incident ray, and the angle *i* made between it and the normal—the straight line drawn perpendicular

to the surface at the point of incidence—is known as the angle of incidence.

The reflected ray is R, and the angle, *r*, between it and the normal P is called the angle of reflection.

The laws of reflection may then be stated as follows:—

I. The reflected ray lies in the same plane as the incident ray and the normal, but on the opposite side of the latter.

II. The angles of incidence and reflection are equal.

It may be mentioned that if a ray is incident normally on a mirror it will be reflected back along its own path, since in this case both the angles of incidence and reflection are equal to zero.

Regular reflection may be recognised by the formation of an image of the source of light, the eye unconsciously producing the reflected rays backwards until they appear to diverge from a point the same distance behind the mirror as the luminous object is in front of it.

A knowledge of the laws of reflection will be found to be of importance when the construction of reflectors which are required to produce a beam of light in some given direction is undertaken.

Diffused Reflection.—When a beam of light falls upon a rough unpolished surface the reflection is no longer regular, but the rays are scattered in all directions.

The surface on which the light falls appears luminous, and behaves as if it itself were the source of light.

In such cases no image of the source is formed, and if the surface is without polish of any kind the quantity of light reflected is greatest in the direction of the normal to the surface.

What actually does take place during diffused reflection is as follows: The separate incident rays are all reflected according to the laws enumerated above, but owing to the fact of the various parts of the surface being inclined at different angles to these rays, the latter are reflected in all directions, or a beam composed of scattered rays results.

This is indicated in Fig. 2, which shows a parallel beam falling upon a diffusing surface, such as that of a sheet of white paper. The reflected beam is seen to consist of a number of scattered rays.

Diffused reflection takes place from the walls and ceiling of a room, and a considerable increase in what is termed effective candle-power can be obtained by employing paper and plaster having a high coefficient of reflection.

The practice of lighting rooms by means of diffused reflection is becoming more and more common, the absence of shadows

being appreciated by many, although partly by reason of the lack of contrast the room appears less well lighted than it really is.

Perhaps the best feature of the system lies in the fact that the brilliant light sources are themselves invisible, and can thus produce no harmful effects on the eyes of observers, for it cannot be too strongly impressed upon all users of artificial light that glare must, at all costs, be avoided, and powerful sources placed out of the direct line of vision.

The question of diffused reflection, as will be more fully indicated in a later chapter, is an exceedingly important one, and should always receive very careful attention when a lighting scheme

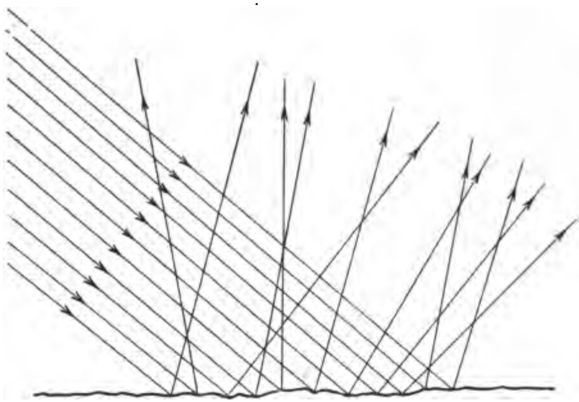

FIG. 2.—Diffused Reflection.

is taken in hand, both the colour of the walls and ceiling, as well as that of the decorations, requiring judicious selection.

Absorption.—It has been stated previously that when light falls upon a surface part of the light is reflected, some transmitted, while the rest is absorbed or wasted.

No bodies are perfectly transparent, and it is on account of the absorption taking place that white light generally becomes coloured on traversing a sufficient thickness of the material.

Dull black surfaces, such as those of velvet and black cloth, are examples of good absorbers.

Light falling upon such surfaces is practically all absorbed, and beyond raising the temperature of the surface slightly, performs no useful purpose.

Frequently the walls and ceiling of a room will be so thickly coated with dirt and dust, that practically the whole of the light

falling upon them is wasted. If the room under these conditions is found to be insufficiently lighted, a change in its colour-scheme, may have the desired effect.

This is well illustrated in Fig. 3, which shows two small rooms of exactly similar dimensions receiving identical illumination.

The walls of the room on the left are dark, and absorb practically the whole of the light falling upon them, while those of

FIG. 3.—Two rooms receiving identical illumination.

the room on the right, having a high coefficient of reflection, reflect most of the light.

The result is that one room appears well lighted while the other, by reason of the absorption taking place, appears badly lighted.

All materials possess absorptive power in a greater or less degree, and absorption plays a very important part in determining the value of materials that are to be used as reflectors and diffusers of light.

All shades employed in electric lighting schemes absorb more or less of the light falling upon them. Such shades are intended

generally to serve three purposes. In the first case they must diffuse or soften the light, and in this manner prevent a glaring illuminant from being in the line of vision ; further, they must be more or less ornamental, depending upon the surroundings, while frequently they are required to direct the light in some particular direction.

Very dense material absorbs so much of the light as to seriously impair the overall efficiency, the same remark applying to highly coloured material, while the sacrifice of a sufficiently good illumination for art's sake should not be entertained if eye-strain is liable to result.

The spectra of illuminants can be successfully balanced by the correct use of absorbing shades or screens, and hygienic conditions conformed to.

Lastly, it must be remembered that an accumulation of dust acts as a very good absorber, and it would be well to insist on all globes and shades being kept perfectly clean.

Transparent Body.—A transparent body is one through which objects can be distinctly seen.

The glass bulbs usually employed in the manufacture of incandescent lamps are transparent, and as such allow a clear view of the filament to be obtained.

Translucent Body.—A translucent body is one through which light can pass, but through which bodies cannot be distinctly seen.

Translucent globes are used extensively in electric lighting to prevent a direct view of a luminous filament from being obtained.

A transparent body, such as a clear glass bulb, may be rendered translucent by sand-blasting, or by the process known as frosting, and this device, of course, is frequently resorted to when the lamps of necessity must be so installed that a direct view of them is a possibility.

Opaque Body.—An opaque body does not allow light to pass through it at all.

Such bodies are largely used in the indirect system of lighting, lamps being surrounded by bowls of opaque material.

Opaque surfaces are largely employed for general reflection purposes, the majority of the electric-car head lights, for instance, being backed by silvered opaque reflectors.

CHAPTER II

ILLUMINATION AND ITS MEASUREMENT

WE have seen in the preceding chapter that a luminous body, such as the filament of an incandescent lamp, radiates light in all directions, and the question arises as to what happens when this light falls upon a surface.

In general terms it may be stated that whenever light falls upon a surface the surface is said to be illuminated, the illumination depending solely upon the quantity of light falling upon the surface and in no way upon the nature of the latter.

In Fig. 3 the two rooms shown have the same illumination, or the quantity of light received by each in a given time is the same.

The illumination does not depend upon the colour-scheme, although, as is clearly shown, the latter governs the result, in that one room appears well lighted, while the other is obviously far from being in this condition.

In the same way adjacent surfaces of white paper and black velvet may receive equal illumination. The white paper, having a high coefficient of reflection, will reflect the greater portion—perhaps 80 per cent.—of the light falling upon it, and in consequence appear well lighted, whereas the velvet will absorb practically the whole of the light incident upon it, the light being wasted and merely raising the temperature of the material.

From the above considerations it is clear that the surface may be one with a high reflection coefficient, or one possessing good absorbing powers, without in any way affecting the illumination, and great care must be taken to ensure that the term illumination always has its correct meaning assigned to it. Further, it may be observed that the same illumination may, under different conditions, produce widely varying results, the result in general, as will be indicated later, depending upon the colour-scheme employed.

Candle-Power.—The accurate measurement of illumination requires a knowledge of both candle-power and the unit of distance

employed. The latter in English-speaking countries is the foot, and requires no further defining.

Candle-power is measured simply as an intensity in any direction, and the expression signifies the unit of luminous intensity. The term candle-power was originally derived from the luminous intensity of the candle flame, the candle being generally supposed to yield a flame of unvarying intensity. That this is far from being the case has, however, been repeatedly demonstrated, unwearying research establishing the fact that the candle as a true standard is impossible.

English Parliamentary Candle.—The English candle was set up about 1860 as an official standard to be used for the purpose of testing gas. It is described as a spermaceti candle burning 120 grains per hour, six candles equalling the mass of one pound; but it is clear that exact reproduction is impossible, and a wide variation in intensity must inevitably result.

International Candle.—The unit that has been adopted as the international unit of candle-power by the countries of Great Britain, France, and the United States of America, is called the "International candle."

Such a candle is defined as being equal to 1 Pentane candle, or 1·11 Hefner units, the Hefner being the German unit and denoting the luminous intensity of the Hefner lamp under standard conditions.

As it is the practice of German and other Continental lamp manufacturers to rate their products in terms of the Hefner unit, it may not be out of place at this point to draw the reader's attention to the corresponding values in British units.

Thus since 1 Hefner unit = ·9 British units, a 16 candle-power lamp (Hefner) would be rated at $16 \times \cdot 9 = 14{\cdot}4$ candle-power (British), and this must not be lost sight of in making efficiency comparisons.

Foot-Candle.—The foot-candle is the unit of illumination, and is defined as the illumination produced by a source of one candle-power on a surface everywhere one foot distance from the source.

Frequently, though more generally in American literature, the foot-candle is defined as an illumination of one *lumen* per square foot, this definition involving a consideration of luminous flux.

Since the candle-power of a source varies with the direction, there is much to be said for the latter method of measurement, and this being so a brief discussion of luminous flux appears necessary.

Flux of Light or Luminous Flux.—Imagine a luminous source radiating flux with unit intensity in all directions. Such a source will be a point source of unit intensity, or one candle-power, the intensity in all directions being the same.

From the source unit flux will be given out within each unit solid angle, the total luminous flux being equal to that within each unit solid angle multiplied by the number of such angles about the source.

The unit of luminous flux defined above is known as the *lumen*, and thus from the source the total flux of light emitted must equal 4π lumens.

If such a source be surrounded by a sphere of radius equal to one foot, the total flux emitted will be intercepted by the surface of the sphere, and the flux incident upon each square foot of the surface will be given by

$$\begin{aligned}\frac{\text{flux}}{\text{area}} &= \frac{4\pi}{4\pi} \text{ lumens per square foot} \\ &= 1 \text{ lumen per square foot}\end{aligned}$$

since the flux is 4π lumens and the area 4π square feet.

According to the first definition of the illumination unit it is clear that the illumination at all points on the surface of the sphere is the same and equal to one foot-candle, all points being the same distance—one foot—from the source of one candle-power.

According to the flux method of regarding the question, the flux incident upon each square foot of surface is equal to one lumen, and since at each point on the square foot the illumination is one foot-candle, the following definition of the lumen must hold for agreement.

Lumen.—The lumen is the flux of light which produces an average illumination of one foot-candle over one square foot.

The illumination recommended as suitable for all average desk work is 3 foot-candles, and if the area of the desk under consideration is 12 square feet the total flux required will be $3 \times 12 = 36$ lumens.

Further examples will be afforded in a later chapter.

Mean Spherical Candle-Power.—In practice it is found that the intensity of a light source is never the same in all directions.

The point source is a theoretical standard only, although many incandescent metal filament lamps yield an almost constant intensity in a horizontal plane.

Imagine a luminous body to be surrounded by a sphere and

a number of points uniformly distributed over the surface of the latter to be taken.

If the candle-power be now measured in the direction of radii to each of these points, the average of all the intensities so found is called the mean spherical candle-power of the source.

It has already been pointed out that most metal filament lamps yield an almost constant horizontal intensity, and as it is the general custom to rate such lamps in terms of their mean horizontal candle-power, a knowledge of the mean spherical candle-power, or M.S.C.P., is not of much importance. Its value can, however, be found by multiplying the mean horizontal candle-power by a factor which varies between 0·8 and 0·85.

Here, again, it must be pointed out that many writers regard mean spherical candle-power from a flux standpoint. A source whose average intensity in all directions is unity emits a flux equal to 4π lumens, and if I_0 is the M.S.C.P. of a source, then the relation between I_0 and luminous flux is given by: flux $= 4\pi I_0$.

The results arrived at are in general the same, and there is much to be said for both methods of regarding the question, although perhaps the idea of a simple average of the candle-powers in all directions is the better way of regarding mean spherical candle-power.

Law of Inverse Squares.—The illumination at a point is clearly directly proportional to the candle-power of the source in its direction, and it remains to be seen in what way it depends upon the distance of the surface from the source.

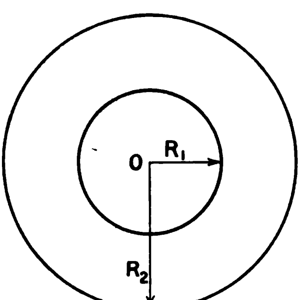

FIG. 4.

In Fig. 4 O represents a point source of light, which we may consider to be a metal filament lamp if end effects are neglected. This assumption is justified if the distance at which the calculations are made exceeds some ten times the maximum dimension of the filament, which distance will not exceed three feet.

Imagine the source to be surrounded by a sphere of radius R_1, and further let I represent the candle-power of the source.

The total flux of light emitted will be intercepted by the surface

of the sphere, and calling the flux Q, the illumination, or the flux incident upon unit area of the surface, will equal

$$E_1 = \frac{Q}{4\pi R_1^2}$$

since $4\pi R_1^2$ is the area of the surface of the sphere.

Now imagine the sphere to be replaced by one of a greater radius, R_2.

The new surface will, in its turn, intercept the total flux emitted, the illumination being

$$E_2 = \frac{Q}{4\pi R_2^2}$$

Comparing these values, it is seen that

$$\frac{E_1}{E_2} = \frac{\frac{Q}{4\pi R_1^2}}{\frac{Q}{4\pi R_2^2}} = \frac{R_2^2}{R_1^2}$$

or the illumination produced by a source of light is inversely proportional to the square of the distance from the source.

Otherwise.—Since I is the candle-power of the source, supposed constant in all directions, the mean spherical candle-power is I, and the flux of light emitted, $4\pi I$ lumens.

The light coming through every square foot of surface area in the case of the sphere of radius R_1 will equal

$$\frac{4\pi I}{4\pi R_1^2} = \frac{I}{R_1^2} \text{ lumens}$$

and thus by definition the average illumination over the surface of the sphere is $\frac{I}{R_1^2}$ foot-candles.

With regard to the second sphere the light coming through every square foot of area will equal

$$\frac{4\pi I}{4\pi R_2^2} = \frac{I}{R_2^2} \text{ lumens.}$$

And the average illumination over the surface will obviously equal $\frac{I}{R_2^2}$ foot-candles.

Comparing the values obtained, it is seen that the illumination is inversely proportional to the square of the distance from the source.

As an example it may be noted that the illumination produced by a 25 candle-power lamp at a distance of 5 feet is

$$\frac{25}{5^2} = \frac{25}{25} = 1 \text{ foot-candle}$$

on a surface everywhere at right angles to the rays of light.

This very important fundamental law is known as the law of inverse squares, and is of great value in all illumination calculations.

Strictly speaking, it applies only to point sources of light, that is, to luminous bodies of no appreciable magnitude, but, as before stated, the law holds to a close degree of approximation if the distance from the source exceeds some ten times its maximum apparent dimension.[1]

Law of Cosines.—In the calculations made so far the reader will have observed that the illumination at all points on the surface of the sphere considered was the same. This was due to the fact that all points directly faced the source of light, and were at equal distances from it.

The illumination produced by a source of light on the surface of a table directly underneath it will be inversely proportional to the square of the distance of the source from the table.

Thus, if the illumination required directly beneath a lamp, whose intensity in the required direction is 32 candle-power, is 2 foot-candles, the distance the lamp must be suspended above the table will be given by the equation

$$E = \frac{I}{D^2}$$

substituting $$2 = \frac{32}{D^2}$$

or $$D^2 = 16$$

whence $$D = 4 \text{ feet.}$$

The surface under consideration will, however, be found more often to be inclined to the direction of the rays of light, and the illumination then decreases.

In Fig. 5 the screen S_1 of area A intercepts the parallel beam of light indicated by the arrow-heads. If Q is the flux incident on S_1 the illumination will be given by

$$E_1 = \frac{Q}{A}$$

[1] "Illumination and Photometry," Wickenden, 1910.

Let S_1 be now removed and its place taken by S_2. The same flux Q, that was intercepted by S_1, will now in its turn be intercepted by S_2.

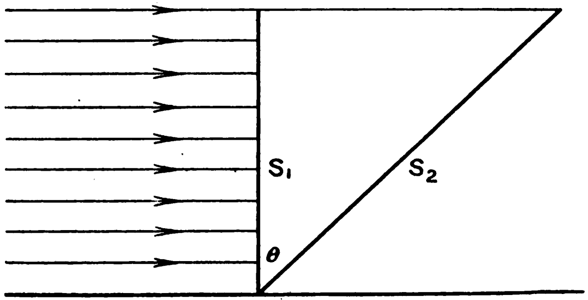

FIG. 5.

The area of S_2 is, however, greater than that of S_1 and equals

$$\frac{A}{\cos\theta}$$

This means that the illumination being spread over a greater area the value will be decreased, and will equal

$$\begin{aligned} E_2 &= \frac{Q}{S_2} \\ &= \frac{Q}{\frac{A}{\cos\theta}} \\ &= \frac{Q}{A}\cos\theta \\ &= E_1 \cos\theta \end{aligned}$$

The angle θ is equal to the angle of incidence, or is the angle made between any ray and the normal to the surface at the point of incidence.

The result obtained, which is known as the cosine law, may then be stated as follows:—

The illumination decreases as the cosine of the angle of incidence.

From the law of inverse squares and the cosine law the illumination at any point may be expressed in terms of the intensity of the source in the direction of the point, the distance between the point and the source and the angle of incidence θ.

Thus illumination

$$= \frac{I}{l^2} \cos \theta \text{ foot-candles}$$

where I is the intensity or candle-power of the source in the required direction, l the distance in feet between the point and the source, and the angle of incidence.

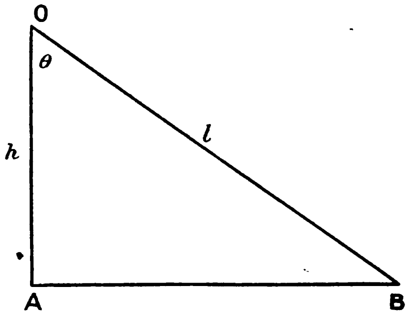

FIG. 6.

In Fig. 6 O is a source of known candle-power, I, and is suspended at a height h above the working plane, the latter being the surface on which the chief illumination is required, and generally assumed to be 2 ft. 6 in. above the floor. B is the point at which the illumination is required, and l its distance from the source.

From the law of inverse squares and the cosine law the illumination at B in the plane AB is seen to be

$$\frac{I}{l^2} \cos \theta$$

From the figure it is clear that

$$l = \frac{h}{\cos \theta}$$

whence the illumination

$$= \frac{I}{\frac{h^2}{\cos^2 \theta}} \cos \theta$$

$$= \frac{I}{h^2} \cos^3 \theta$$

and is seen to vary as the cube of the cosine of the angle of incidence for a given candle-power and height of lamp.

The above case dealing with the horizontal illumination produced on a plane by a source of light radiating uniformly in all directions is a very important one, and will be found of great practical use.

Tables of $\cos^3 \theta$ are to be found (see Appendix), and then since I and h are fixed for any given installation, the construction of the illumination curve is a very simple matter, as will be indicated later.

Intrinsic Brilliancy.—The intrinsic brilliancy of a light source is generally expressed as the candle-power per square inch of surface exposed in a given direction.

Sources of high intrinsic brilliancy should never be placed in the direct line of vision, the eye, according to various authorities, being capable only of regarding with equanimity sources whose candle-power per square inch does not exceed some 3 to 5.

Sources, whose intrinsic brilliancy exceed the upper limit, should be screened or shaded in such a manner that they are themselves invisible.

The following values for the intrinsic brilliancy of various sources are given by Ives and Luckiesh :—

Source.	Intrinsic Brilliancy.
1. Sun at zenith	600,000 C.P. per sq. inch.
2. Nernst glower	800–1600 ,, ,,
3. Tungsten lamp— 1·25 watts per candle .	1000 ,, ,,
4. Tantalum lamp— 2 watts per candle . .	750 ,, ,,
5. Carbon lamp— 3·1 watts per candle .	480 ,, ,,
6. Carbon lamp— 3·5 watts per candle . .	375 ,, ,,
7. Carbon lamp— 4 watts per candle . .	300 ,, ,,
8. Frosted incandescent lamp— 25 watts tungsten . .	4–8 ,, ,,

CHAPTER III

STANDARD LIGHT SOURCES

WITH the introduction and increased use of gas for illuminating purposes, it became necessary to express the intensity of the new illuminant in terms of one more generally known at the time.

In other words, a standard light source was required with which intensities could be compared and the tested source expressed in terms of the standard one.

Measurement consisting of a comparison of one quantity with another, it is clear that one of the two quantities must be invariable, or of such a nature that variations in its value can always be calculated and allowed for.

The invariable source, or the standard, is determined in value by the accuracy with which it can be reproduced.

A unit as set up at some recognised research laboratory may be of great value in the hands of a few trained observers, but quite useless to the multitude of testers at large, for the simple reason that in many cases the adjustments and precautions necessary to insure a true reading cannot be attempted.

Other things being equal, the more simple the source the more chances it has of becoming recognised as a standard, for it can be set up and its intensity determined by the comparatively unskilled.

If a source exists that can always be relied upon to yield exactly the same intensity, it may be dignified by the name of a primary standard, but as a vast amount of research has so far failed to produce such a source, no real primary standard can at the present moment be said to exist.

Several of those investigated, however, can be reproduced with approximate accuracy, and their intensity determined by careful calculation. Such are largely used as primary standards, and are employed in the calibration of others which are somewhat less accurate, but sufficiently so for average work.

The latter are known as secondary standards, and in many

cases are themselves used to calibrate working standards for routine testing.

At the time of gas introduction the candle was in general use as a luminant, and it was only natural that the intensity of the gas flame should be expressed in terms of that of the known source, or in candle-power, the term at that time denoting the luminous intensity of the candle-flame.

Candle-power is measured as an intensity in any direction, the direction generally understood, if no particular one is specified, being the horizontal, and care should be taken to attach no other meaning but that of intensity to the expression candle-power.

The candle-power of a luminous source then simply means the intensity of the source in a horizontal direction, although with incandescent lamps it is usual for the makers to rate them in terms of their mean or average horizontal candle-power.

At this point it may be well to note that a distinction must be made between the unit employed and an existing standard. At first the term "candle-power" denoted the luminous intensity of the candle-flame, as will be explained later, but it now stands for a particular value, and the International Candle or the English Pentane Standard Candle, is therefore a unit and not a standard.

The candle, though worthy of note through having furnished the most popular conception of a light-unit for over a century, has been proved again and again incapable of yielding an intensity of the fixed magnitude required of a standard.

In common with all flame sources its intensity suffers through atmospheric variations. Thus variations in pressure, humidity, and in the amount of carbon dioxide and oxygen present produce changes in the intensity for which corrections cannot always be applied.

The English Parliamentary candle, to which reference has been made previously, was set up in 1860 as an official standard for the purpose of gas-testing. The candles are specified by weight, six equalling the mass of one pound, and are manufactured of spermaceti.

Such candles, when burning at the standard rate of 120 grains per hour, are assumed to yield their maximum intensity, and corrections can be applied to account for variation in atmospheric conditions from normal.

The idea of employing such sources seems somewhat crude when the present-day standards are considered, but, nevertheless, candles properly constructed and used are capable of a considerable degree of accuracy.

Allowance can be made for variations in the rate of burning,

and a fairly uniform intensity in a direction at right angles to the flame can be obtained.

Candles are still used in gas-testing, and with care are capable of yielding fair results, but for no really accurate work is their use entertained at the present.

We thus find the candle giving place as a standard to several flame sources of various designs and intensities, the most important ones being the Hefner and the Pentane standards.

FIG. 7.—Hefner Lamp.

The Hefner Lamp.—In Germany the unit of luminous intensity is the Hefner, the expression denoting the intensity of the Hefner lamp burning under standard conditions.

The lamp is the official German standard, and its dimensions are very accurately set forth to enable reproduction to be undertaken. Being a flame source the intensity varies with atmospheric changes, but as such have been the subject of much study corrections for the same can readily be applied.

The lamp, which is indicated in Fig. 7, is of simple construction. The reservoir contains purified amyl-acetate, into which dips a wick held in a German-silver tube of the exact dimensions set forth in the specification.

An adjustment consisting of toothed wheels worked by worm gear controls the height and permits of accurate flame setting. This flame, which is circular in cross-section, resembles in general appearance that of a candle, and to be accurate must be exactly 40 mm. high. The height may be checked by noting the position of the image formed on the ground glass window, by means of the lens which is supported as shown in the figure.

Great care and a considerable amount of skill are necessary when making use of the Hefner lamp as a standard source, errors resulting if an incorrect flame height is maintained.

Further, the flame must be carefully screened since, being subjected to very little draught, it is readily affected by stray air currents, and this leads to flickering and difficulty in adjustment.

The advantages of the Hefner as a standard are fairly numerous. In the first place it can be readily reproduced with great accuracy from the standard specification, an essential feature of a standard with any pretensions to the name, while, further, its intensity can be corrected by known formulæ if the conditions are other than normal.

The liquid employed—amyl-acetate—is easily obtained in the pure state, and as it vaporises at a low temperature the combustion is not influenced by wick considerations.

In addition the lamp is small, simple and inexpensive, much facilitating duplication and setting.

Against the use of this particular unit may be urged its low intensity—0·9 International candle-power—and the reddish colour of the flame which tends to introduce inaccuracies at low intensities.

The Harcourt Pentane Lamp.—In Great Britain, and for gas-testing in America, pentane is largely used, the standard of candle-power now in use in the former country being the "Vernon-Harcourt" 10 candle-power Pentane Lamp. One-tenth of this value is equal to the new French standard the "bougie décimale" and the American International candle.

Pentane is obtained from petroleum, and is a volatile hydrocarbon which when mixed with air forms a gas of high illuminating power.

In the recognised standard the pentane is contained in a

rectangular box which is shown situated at the top of the lamp. Air is drawn over the surface of the liquid contained in the tank, and in its passage becomes saturated with heavy pentane vapour, and then falls through a pipe shown to an Argand burner.

The flow is regulated by taps which can be clearly seen, and a chimney is provided to furnish a sufficient draught to ensure steady burning, no wick being used. With regard to the chimney the Pentane standard is much superior to the Hefner, as screens must be arranged round the latter to prevent flickering.

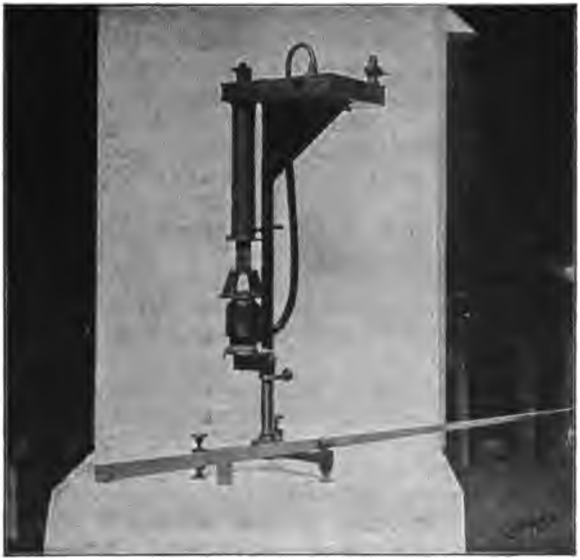

FIG. 8.—Ten Candle-power Harcourt Pentane Lamp.

Under normal conditions, and with the height of the flame correctly adjusted, the Pentane standard is rated at ten candle-power.

Corrections, as with all flame standards, must be applied to allow for atmospheric changes, and in this respect the Pentane is inferior to the Hefner, the corrections for barometric changes being much greater in the case of the former than in that of the latter.

The Pentane yields a whiter light than that of the German standard, and its intensity being eleven times that of the Hefner

it is more suitable for testing units of the magnitude in present day use.

These factors, taking into account also the greater ease of adjustment, outweigh the disadvantages of complicated construction and increased correction factors.

The Carcel Lamp.—The gas standard in France is the Carcel lamp, a lamp burning colza oil and yielding an intensity of 9·62 International units (Fig. 9). It is the oldest of the recognised standards, but somewhat difficult to manipulate.

Relative Values of the Standards.—It having been estab-

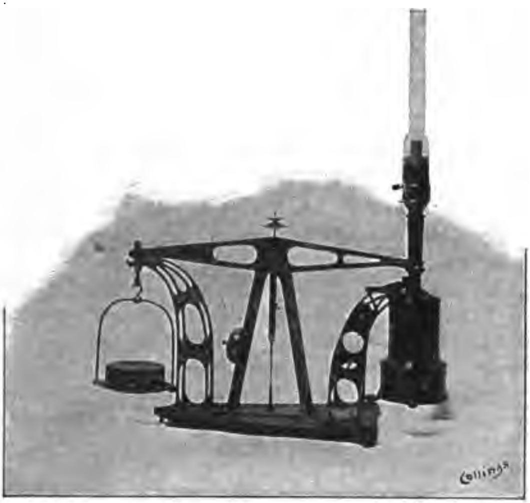

FIG. 9.—Carcel Lamp.

lished that the International candle should be defined as equal to one Pentane candle, the relative values are as follows :—

1 International candle = 1 Pentane candle
1 International candle = 1·11 Hefner
1 International candle = 0·104 Carcel
or
1 Hefner = 0·9 International candle
1 Carcel = 9·62 International candle.

Secondary Standards.—Flame standards are of great value as ultimate standards and for gas-testing generally.

In the latter case the variations that occur in intensity due to atmospheric changes are not of much account, as the source under test is influenced by the same variations, and the changes may be assumed to cancel out one against the other.

In electrical testing, on the other hand, the corrections would have to be applied, as atmospheric variations would in no way influence the candle-power of an electric incandescent lamp.

Flame standards for such work are then unsuitable, except in special cases. The corrections entail considerable labour, and the manipulation of the sources calls for no uncertain amount of skill. For routine work such sources are then superseded by secondary standards of the same nature as the lamp under test, the secondary standards being themselves periodically tested against some known recognised standard.

Incandescent lamps should be compared with a similar standardised lamp.

If a glow lamp is compared with a flame source as standard, numerous errors may be introduced, due on the one hand to atmospheric changes affecting the intensity of the standard, and on the other hand to variations in the supply pressure that of the lamp under test.

Incandescent electric lamps with aged filaments, or filaments that have been subjected to a preliminary run, are found to make admirable testing standards. Such lamps should never be over-run, as their intensity is found to be permanently charged if such is the case, but, on the other hand, if run at a stipulated reduced pressure a constant intensity for a protracted period can be relied upon.

The glow lamp introduced by Dr. Fleming is generally recognised as the most reliable electrical standard to be obtained.

The lamp is a large bulb one with a single carbon filament. The large bulb prevents blackening, or at least allows it to take place very slowly, and as the loss in candle-power is almost entirely due to this cause, a constant intensity is maintained.

The lamps are first compared with a recognised primary standard, generally by the National Physical Laboratory authorities. The exact current and pressure at which the stated candle-power is produced are given, and if these values are carefully reproduced and never exceeded the lamp can be relied upon to be exceedingly accurate.

Periodical re-testing is required, however, as the filament charges with use, and the intensity, of course, suffers from the charge.

A further disadvantage lies in the fact that an unvarying source of supply is required, which means that a special testing

battery of large capacity must be installed and accurate potentiometer current measurements must always be made.

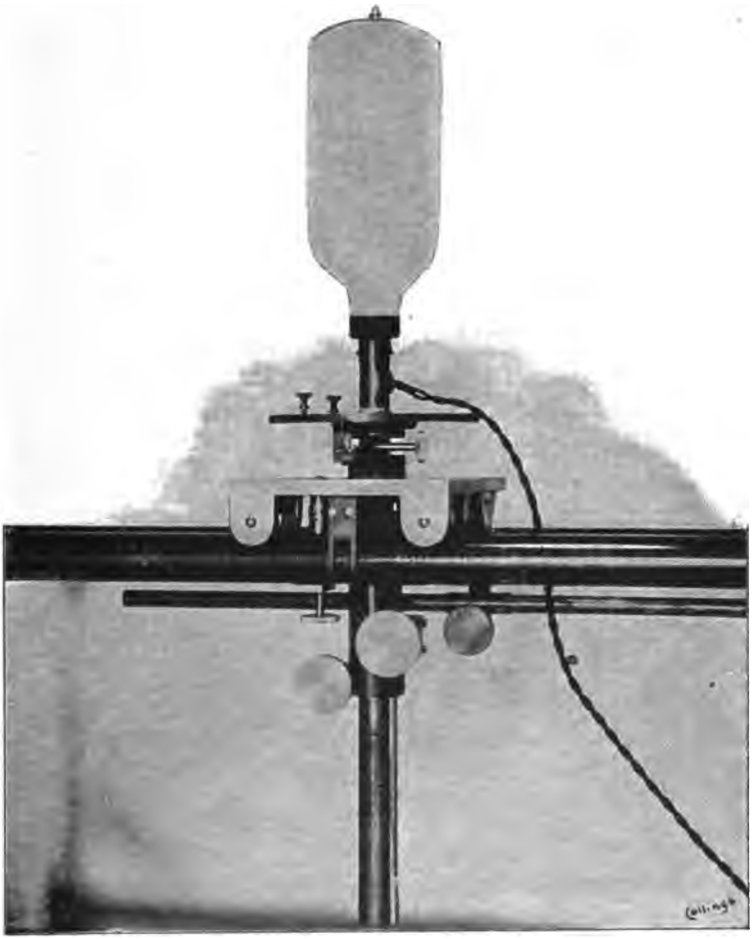

FIG. 10.—Large Bulb Fleming-Ediswan Lamp.

When once the necessary apparatus has been set up, however, the lamp is easily manipulated, and the author has found no difficulty attending its use (Fig. 10).

It is not necessary, of course, to always employ such standards during routine testing, as other lamps can be standardised, using the sub-standard for the time being as a standard.

If such lamps are frequently checked they will give sufficiently accurate results, and the standard, being used only for short periods during standardisation, will last without re-testing for a much longer time.

An incandescent lamp that is to be used as a secondary

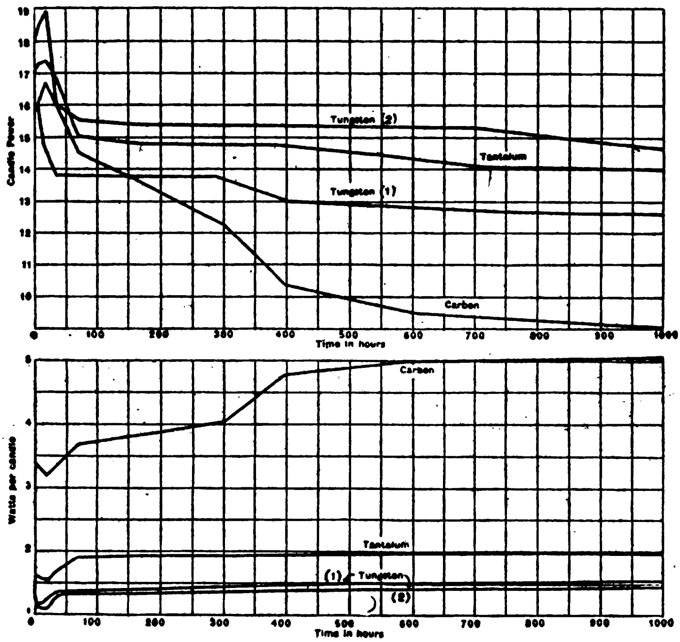

FIG. 11.

standard should be aged by a run of not less than 100 hours. This is to ensure that the period of instability has been passed, as it is well known that the candle-power of incandescent lamps always increases during the initial portion of their lives.

Several lamps should be tested at the same time, care being taken to ensure a constant pressure being maintained.

The candle-power should be ascertained from time to time, and if a curve be plotted the steady period can be observed.

Such a curve is shown in Fig. 11, and it will be seen that for some hundreds of hours the candle-power of the tungsten lamp remains practically constant.

Such lamps would appear to be superior to ordinary carbon lamps for sub-standard purposes, and from a study of the lamp characteristics the practice of running at constant current would appear to be the correct one.[1]

[1] "Lamp Characteristics," D. H. Ogley. *Electrical Review*, Sept. 20, 1912.

CHAPTER IV

PHOTOMETRY AND PHOTOMETERS

MEASUREMENT being the foundation of all science, it is necessary, in order that light and illumination may be adequately dealt with, to devise some means whereby the same may be accurately measured.

Photometry.—Photometry is the branch of science that deals with the measurement of these quantities.

Photometry is the measurement of a sensation, and as such differs in many ways from the ordinary measurements with which the engineer is familiar.

The eye is the organ actively engaged, and itself sets a limit to the accuracy with which photometric measurements can be carried out, as practically all the instruments employed depend upon the correctness with which the eye is enabled to judge of the equality of the illuminations of two surfaces.

Unfortunately there is no fixed standard of vision, and individual experimenters are bound to introduce personal errors into their calculations, the extent of the errors depending upon the particular state of their vision at the time of conducting the experiment.

It is found, however, that with normal sight the errors can with practice be reduced to less than 1 per cent., and if this condition cannot be satisfied the operator is unsuited for accurate work.

When undertaking photometric measurements it should be understood that the eye must not be subjected to the action of exposed light units, but must be kept in a sensitive condition, which entails the complete screening, as far as the eye is concerned, of the standard and the source under test. Two operators should work together, the lamps, etc., being manipulated by one of them, and the other keeping his eyes in a sensitive condition by refraining from direct observation of the sources.

Measurement of Candle-Power.—In a former chapter

reference has been made to the fact that a surface is said to be illuminated when light falls upon it, the illumination depending simply upon the quantity of light falling upon the surface.

Candle-power is measured by comparing the illuminations of two screens, one illuminated by the luminous body under test, and the other by the standard source, the eye being called upon to judge of the equality of the illuminations.

In making a measurement the screen and the light sources are suitably arranged, as will be explained later, and the distance between the screen and source under test adjusted until, as far as the eye can judge, the illuminations of the two surfaces in view are equal.

The intensities of the two sources may then be compared by a simple application of the law of inverse squares.

Thus, if balance is obtained when the standard is two feet, and the tested source six feet from the screen, the candle-power of the lamp under test will be nine times that of the standard.

Mean Horizontal Candle-Power.—The intensity so found signifies merely the candle-power of the source in a particular direction. The direction usually understood is the horizontal, and if the candle-power is measured in several directions in the same horizontal plane, and the average of the measurements so found taken, the figure obtained is generally known as the mean horizontal candle-power, or M.H.C.P., of the source, in terms of which it is the usual custom to rate all incandescent lamps.

Photometers.—A photometer is an instrument by means of which the candle-power of a source of light may be ascertained, the many forms taken by this instrument being due to the various arrangements made for the simultaneous viewing of the two similar surfaces, illuminated by the light sources to be compared.

A standard light source is, of course, necessary, as all true measurements deal with the comparison of one quantity with another of fixed magnitude, the standard light source of known intensity being known in this case, and in terms of which the intensity of the source under test is expressed.

The simplest photometer that can be imagined is a wedge-shaped screen, whose sides are diffusing surfaces similar in all respects, and illuminated by the two sources under comparison.

The arrangement is indicated in Fig. 12, and it will be observed that the rays meet the screen in such a manner that the angles of incidence are equal.

Now let I_1 and I_2 be the respective intensities of the sources, I_1 being that of the standard, and therefore known; and I_2

that of the source required; and, further, let θ be the angle of incidence.

Then, calling E_1 and E_2 the illuminations of the two sides of the screen, it follows from Chap. II. that

$$E_1 = \frac{I_1 \cos\theta}{l_1^2}$$

$$E_2 = \frac{I_2 \cos\theta}{l_2^2}$$

By simply adjusting the position of the screen equality of illumination may be obtained, and when this has been established it follows that

$$E_1 = E_2 = \frac{I_1 \cos\theta}{l_1^2} = \frac{I_2 \cos\theta}{l_2^2}$$

or

$$\frac{I_1}{l_1^2} = \frac{I_2}{l_2^2}$$

whence

$$I_2 = I_1 \frac{l_2^2}{l_1^2}$$

Now, since I_1—the intensity of the standard—is, or should be, accurately known, and since the measurement of l_1 and l_2 presents no difficulty, the intensity I_2 is readily determined.

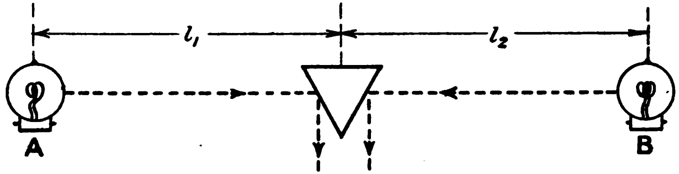

FIG. 12.—Simple Wedge Photometer.

It should be again noted that the measurement so obtained gives the candle-power in one direction only. If the source B be so mounted that it is capable of rotation about a vertical axis its intensity can be measured in several directions in the same horizontal plane, and the average of the readings so found taken to give the mean horizontal candle-power.

In practice the use of the wedge photometer described above is beset with difficulties.

If the angle of the wedge is a large one the illumination of the sides will be much less than it would be if the angle of the wedge were smaller, the trouble being further aggravated by want of careful centring, for one side will then be much brighter than the other.

If the angle, on the other hand, be a small one the side illumination is increased, but the sides are now difficult to observe.

It has been pointed out that for most substances a wedge angle of about 70° gives the best results, but trouble ensues if a sharp edge is not maintained between the surfaces, the photometer being in this case of low sensitiveness.[1]

By reason of these drawbacks other photometers, in which the mode of measurement employed is somewhat similar to that described above, are in demand, perhaps the best known one being that invented by Bunsen.

The Bunsen Photometer.—The screen employed in present-day Bunsen photometers consists of a piece of paper with a grease spot in the centre of it. Such photometers, by reason of the screen construction, are generally known as grease-spot photometers, and the screen as a grease-spot screen.

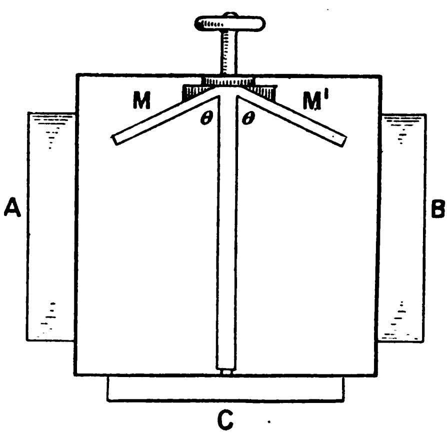

FIG. 13.—Bunsen Photometer, showing Screens and Mirrors.

If such a screen is held between an observer and a source of light, the spot will appear brighter than the rest of the screen, because, being translucent, it allows more light to be transmitted through it than the rest of the paper does.

On the other hand, if the screen is held in such a position that it is seen by reflected light, the spot will appear darker than its surroundings.

The light falling on the spot is transmitted and does not reach the eye, while that falling on the rest of the paper is mostly reflected.

If such a screen be now placed between two light sources, a little reasoning will make it clear that, although the spot does not disappear, equality of illumination will be indicated by both sides being the same in appearance.

[1] Trotter, "Illumination: Its Distribution and Measurement."

To enable the observer to see both sides of the screen at once without changing his position, and to ensure that the views of the two sides are seen at the same angle, two mirrors, M M′, are provided, as indicated in Fig. 13, the angle made between the mirrors and screen being equal.

The screen and mirrors are always mounted in a box with blackened sides to prevent stray light from interfering with the result, the box being provided with two equal openings, A and B, to admit light from the sources under comparison ; and a further opening, C, to permit of the observation of both sides of the screen simultaneously.

The box with its contents is now mounted on a carriage fitted with wheels, and should slide easily along a fixed horizontal scale or photometer bar, as shown in Fig. 14.

The two luminous sources, one the standard, and the other the source under test, are placed one on either side of the photometer,

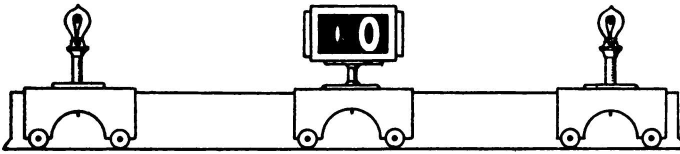

FIG. 14.—Mounted Photometer.

Fig. 14 also indicating the general arrangement. Great care should be taken to ensure that no light except that from the sources in use reaches the photometer screen. Reflections from walls, ceilings, etc., must be avoided, and this result is generally achieved by coating the surfaces mentioned with a lampblack mixture of negligible reflection coefficient. The same result may be obtained by efficient screening of the sources, but the author has found that the eyes remain in a more sensitive condition when the work is carried out in a blackened photometric laboratory.

To measure the intensity of a source, it is necessary then to move the photometer head backwards and forwards until a position is found somewhere between the sources such that both sides of the screen present the same appearance to the observer. The intensity of the source may then be compared with that of the standard by applying the law of inverse squares.

The advantages of the Bunsen photometer are fairly numerous. It is exceedingly simple, is cheap, and parts are readily renewed, while with it beginners can obtain very fair results.

For exceedingly accurate work perhaps the boundary between the spot and the rest of the paper is too ill-defined, rendering it no easy matter to judge of inequality of illumination between the two sides of the screen.

The Lummer-Brodhun Photometer.—A somewhat complicated photometer in use for accurate work is that known as the Lummer-Brodhun.

The screen is one of the special features of the instrument, and unlike that used in the Bunsen photometer, is wholly opaque.

Such screens can be made by compressing magnesia or barium sulphate into a circular hole in a metal plate.

The reflecting and diffusing powers of the surface are good in themselves, but, unfortunately, are much influenced by a coating of dust and dirt, one of the essential requirements of the photometer then being the cleanliness of its parts.

In the later type of instrument the screen is made of a special milk glass which may be occasionally washed without its properties being interfered with.

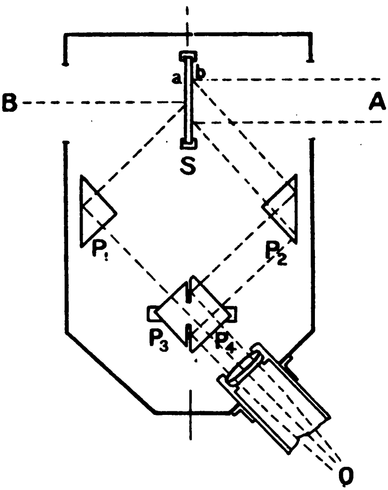

FIG. 15.—Lummer-Brodhun Photometer.

It is well, if the presence of dirt is suspected, to reverse the screen by simply removing it from its place and turning it round, want of symmetry in the readings indicating a change in the reflecting power, and that a new screen is required.

A simultaneous view of both sides of the screen is obtained by employing totally reflecting prisms, as shown at P_1, P_2 in Fig. 15.

The screen and prisms are fixed in a box in the usual manner, the box being mounted on a photometer bar and arrangements being made to admit light from the two sources in the directions shown.

Light incident on the screen S from the source B is reflected on to the prism P_1 and then to the specially prepared prisms P_3, P_4,

the two latter being in contact only at the centre, the contact surface usually being a circular one.

The light from the source B will obviously pass through the circular area of contact and on to the observer, the portion falling on the rest of the base of P_3 being scattered and absorbed by the walls of the box.

The light from the source A falls on the other side of the screen and is reflected on to P_2 and hence to P_3, P_4. That which falls on the centre passes through the area of contact and is absorbed, while the rest is reflected back from the base of P_4, and passes through the lens shown into the eye of the observer.

The side *a* of the screen is seen as an ellipse—side view of the circular area of contact—by reflection from P_1, and surrounding this the side *b* will be seen by reflection from the base of P_4, and also P_2.

If the sources compared are of similar colours the boundary between the two views will disappear when balance is obtained, but if the sources are of different colours, a carbon and metal filament lamp, for example, equal brightness must determine the balancing-point.

In this connection the author has found it of great advantage to employ several standard sources. Thus, for testing carbon glow-lamps an aged carbon lamp is used, while for tantalum and tungsten lamps a specially prepared tungsten lamp is always used.

These secondary standards are themselves calibrated by comparison with a Fleming standard lamp that has been standardised by recognised authorities, and the intensity of all standards is occasionally checked by comparison with a Harcourt Pentane Lamp.

It is much simpler to check a standard, even if the colour does vary, than a large number of lamps of several colours.

Illumination Photometers.—The photometers previously described are capable of one measurement only, namely, that of intensity. As such, their use is limited to the determination of the candle-power of a source of light, and by reason of this fact, they are generally known as candle-power photometers.

Such instruments are useful only in connection with special testing-rooms or laboratories, and beyond the limits of the photometer bar, the photometer itself is a fixture, and as such cannot be used in outside measurements.

It is frequently necessary, however, to measure the illumination at any point, and to study the distribution of illumination over some particular surface, such as that of a road, town square, room

floor, etc., and for such purposes a portable or illumination photometer is required.

Such an instrument must be capable of yielding accurate results when used in the open, or in any other place where special precautions with regard to light-screening cannot be undertaken.

The apparatus must further be capable of use in any position, and in order that accurate information with regard to illumination may be furnished it must be sensitive over a wide intensity range.

Trotter's Photometer.—An instrument which is extremely suitable for illumination measurements and which can also be used for intensity measurements is the Trotter Portable Photometer illustrated in Fig. 16.

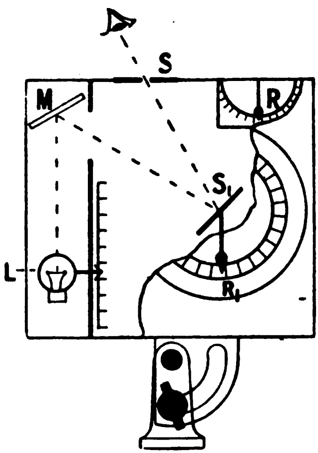

FIG. 16.—Trotter Portable Photometer.

A specially aged straight filament lamp, L, is supplied with current from a battery of accumulators carried in a box, but not shown in the illustration.

The lamp is very carefully standardised, and, being in use only for a few seconds at the actual moment of making an observation, can be relied upon to maintain its correct candle-power for a considerable period.

The question of battery-voltage arises, but as it has been pointed out that the battery will not be discharging for more than twenty to twenty-five minutes during an evening's work, it should, if in good order, maintain a constant pressure during the period.[1]

The importance of good pressure regulation will be apparent when it is understood that the candle-power of a carbon filament lamp varies as a high power of the voltage, a recent figure given being 6·7–7.[2]

A scale is sometimes added to allow for a slight variation in pressure, but this is really not necessary, since a good battery can be relied upon to maintain a constant discharge voltage for the period during which it is in use.

[1] Trotter, "Illumination: Its Distribution and Measurement."

[2] Ogley, *Electrical Review*, Sept. 20, 1912.

In Fig. 16 the light from the lamp L falls upon a fixed mirror, M, from which it is reflected to the screen S_1.

This screen, which has a specially prepared surface to ensure a constant shape being maintained, can be rotated about an axis and viewed through a slit or slits in a specially prepared surface, S, which receives the illumination to be measured.

The illumination of the screen S_1 clearly depends upon its position, and it is possible by rotating the screen to vary the illumination within wide limits.

The method of operation is as follows:—The photometer being fixed in the desired position the screen S_1 is rotated until the best balance possible is obtained, when the lamp is immediately switched off. The illumination required is then read off the dial connected to S_1 in direct illumination units.

To measure the illumination in a plane between the horizontal and vertical the instrument is pivoted, as shown in the sketch, and is capable of rotation through an angle of 90°, the plumb-bob R being used to facilitate setting.

CHAPTER V

LIGHT DISTRIBUTION FROM INCANDESCENT SOURCES

IN previous chapters it has been assumed that candle-power or intensity measurements are always made in one direction only, namely, the horizontal, and that the source under consideration distributes its energy equally in all directions.

In actual practice, however, it will be found that the latter assumption is far from being a correct one, as the only real point sources of light, or sources of equal intensity in all directions, are the heavenly bodies, the sun being the most conspicuous example.

An electric spark may be called a point source under certain conditions, but such is hardly of interest from a lighting standpoint, and it remains to be seen to what extent the actual sources at our disposal differ from the theoretical one already considered.

Light sources in general, including carbon and metal filament lamps, distribute their energy unequally in different directions, and while the intensity measurement in a horizontal direction is of undoubted value as affording a means of comparison between light sources of the same kind, it does not supply all the information required with regard to the light distribution of the source.

Thus the candle-power may be zero in some particular direction and a maximum in another, and to obtain the necessary information with regard to the distribution of light, intensity measurements in various directions must be taken.

If a carbon or metal filament lamp that is in use as a source of light is examined, the unsymmetrical way in which the light distribution takes place will be rendered obvious.

Directly underneath the lamp, for instance, the illumination received on a screen will be much less than that received if the screen be placed at an equal distance from the source and facing it, a horizontal line through the centre of the filament passing through the screen centre.

Light Distribution from Carbon Lamps.—Carbon lamps

in general distribute their light in a very unequal manner. In the case of several 16 C.P. lamps examined by the author, the intensity in the axis direction was never found to exceed 9 C.P., and in the ordinary drop pendant a notable diminution of light occurs in a downward direction.

This fact drew from Dr. Fleming the remark that the common method of hanging carbon lamps head downwards was ridiculous, and he devised the fitting illustrated in Fig. 17 in order that a

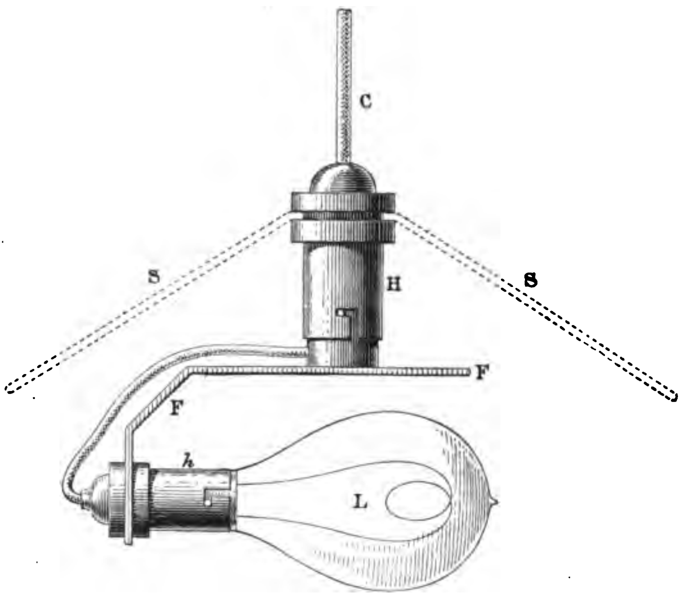

FIG. 17.—Fleming's Pendant.

lamp could be used with its axis in a horizontal position and without the ordinary cord pendant being interfered with in any manner.

Light Distribution from Metal Lamps.—When we come to study the metal lamp, we find that the light is emitted in a horizontal plane in a far more regular manner than it is from a carbon lamp.

This is undoubtedly due to the uniform arrangement of the filament, the several parts of which are grouped in a perfectly symmetrical manner round a central holder.

If a metal lamp be examined it will be found to present practically

the same appearance to the observer from whatever direction it is regarded in a horizontal plane.

On the other hand, a carbon lamp filament presents widely different views as the lamp is rotated, and it is only natural to expect that the horizontal candle-power of metal lamps should be practically constant, while that of carbon lamps should vary with the direction.

Variation in the light distribution does take place, however, in directions above and below the lamp. The holder effectually stops light emission in an upward direction, while theoretically a line filament emits no light in an axial direction.

In practice, however, the presence of several filaments, or parts of the same filament, some distance from each other, improves the intensity in a downward direction, although if the illumination be measured it will be found to be less immediately beneath the lamp than at an equal distance from it in a horizontal plane through the centre of the filament.

From the above considerations it is clear that incandescent lamps do not yield complete uniformity of light distribution, and this being so it is necessary to measure the intensity at various angles with the horizontal.

This may be done by fixing the lamp at the required angle and measuring the candle-power in the usual way, taking care, of course, that the centre of the filament remains in a constant position as regards the photometer bar.

If more convenient, the lamp may remain in a fixed position, and an arrangement of mirrors be employed for the purpose of reflecting the light on to the photometer screen, although this method is usually reserved for arc and gas-mantle testing.

In making such measurements, if it cannot be assumed that the radiation in any angular direction round the vertical axis of the lamp is uniform, means must be adopted whereby the lamp can be rotated at a speed of from 3 to 4 revolutions per second. Such a speed is generally sufficient to eliminate flicker, and in a general way is found to cause no harm to the filament.

The lamp under test is then arranged in such a manner that it can be rotated about a vertical axis in steps of from 10° to 15° at a time and the intensity measured in each direction in the usual manner.

Polar Curves.—Perhaps the best way of exhibiting the results obtained is by means of what is known as a polar curve, constructed by plotting the candle-powers at the various angles considered, with polar co-ordinates.

A polar curve indicates at a glance the intensity in any direction with the horizontal, as is clear from Fig. 18, which is the polar curve of a metal filament lamp examined by the author.

An examination of Fig. 18 reveals the fact that the light emission in an upward direction is practically zero, and for reasons

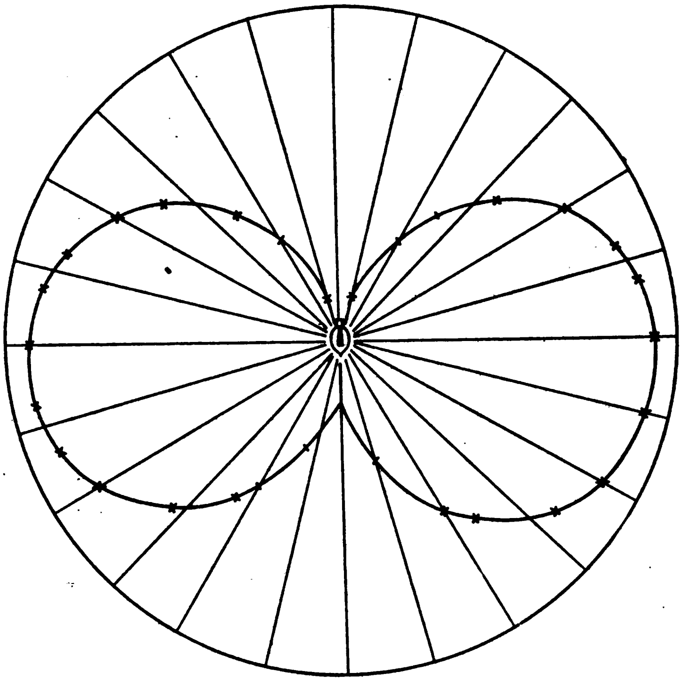

FIG. 18.—Polar Curve.

previously stated the intensity in a downward direction is smaller than that in a horizontal one.

The curve is useful to a certain extent as affording an indication of the light distribution from the source, but the area enclosed in no way indicates the quantity of light emitted.

Care must be taken to attach no other meaning to polar curves than that of intensity indicators in various directions with the horizontal, although, as will be shown later, such curves are of use when the mean spherical candle-power of a source is to be calculated.

Mean Horizontal Candle-Power. — Reference has been made previously to the fact that the intensity in a horizontal plane, more particularly in the case of carbon lamps, varies, and it then becomes necessary to estimate the mean horizontal candle-power, or M.H.C.P., of the source, and in terms of which it has been the custom of manufacturers to rate the luminous value of all incandescent lamps, with the exception of the Nernst.

The M.H.C.P. may be calculated by taking the average of a considerable number of measurements made in a horizontal plane, the lamp being turned round step by step on a vertical axis. It is usual to fix a scale on to the base of the lamp-holder, and the author has found eight readings at angles of 45° to be ample.

The results may be plotted in the form of a curve if such is desired, but the average of the eight readings is generally the only figure required.

The more usual method of estimating the M.H.C.P. of a glow lamp is to spin it a rate of from 3-4 revolutions per second about a vertical axis. By this means every view of the filament is presented in turn to the photometer screen and the average intensity computed.

Mean Spherical Candle-Power.—Mean spherical candle-power, as before stated, must be understood to mean the average intensity in all directions. If an imaginary sphere be supposed to surround a glow lamp, and a number of equally distributed points be taken on the surface of the sphere, then the average of the intensities in the direction of these points is the mean spherical candle-power, or M.S.C.P., of the source in question.

The M.S.C.P. conveys little to the average user of glow lamps, but is of use in accurately describing the performance of a lamp, and therefore an appreciation of its measurement by contractors, etc., is essential.

The polar curve for the source should be at hand at the same time, and taking the two together much valuable information as regards distribution may be arrived at.

Rousseau's Diagram.—Mention has been made of the fact that the M.S.C.P. can be calculated from the polar curve, and the method employed is a construction due to Rousseau.

In Fig. 19 the position of the lamp under test is indicated by O.

To obtain the polar curve the lamp, as previously indicated, is rotated about a vertical axis in steps of 10° at a time, and the intensities found in each of the directions marked off along the radius in that direction. The curve shown drawn through the

points so found is one half of the polar curve, the other half having been omitted, as in general both halves are the same.

To obtain the M.S.C.P. from the polar curve it is now necessary to describe the semicircle XY with O as centre, and to continue the various intensity lines to meet the circumference. One such line is OA, OB representing the intensity in this particular direction.

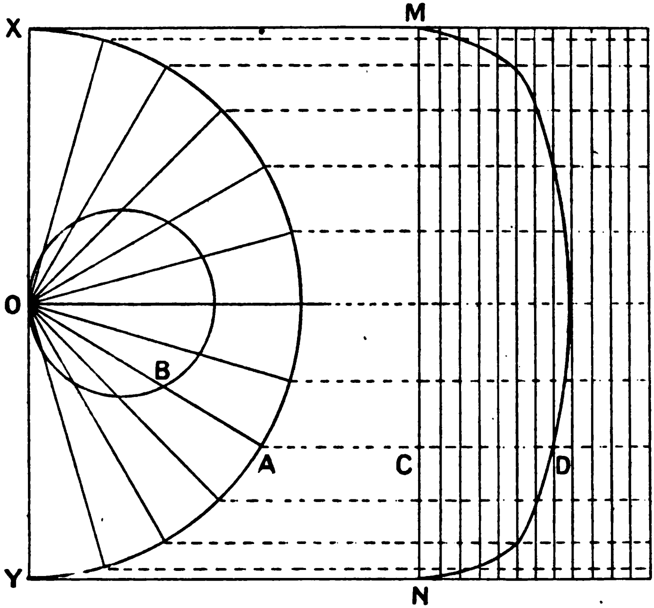

FIG. 19.—Rousseau's Diagram.

From A draw AD to cut MN in C, and mark off CD equal to OB.

CD is thus a measure of the intensity in the direction OB.

Repeat this operation for each polar curve radius, and through all the points obtained draw the curve MDN.

Then the area of the resulting figure divided by its base MN, or, what is the same thing, the mean abscissæ measured from the base, gives the mean spherical candle-power to the same scale as the polar curve.

CHAPTER VI

INCANDESCENT ELECTRIC LAMPS

Carbon Lamps

ONE of the earliest investigators of the incandescent electric lamp was Edison, who appears to have been among the first to appreciate the fact that high-resistance lamps could be worked in variable numbers in parallel on circuits in which the pressure was maintained constant.

At first Edison seems to have concentrated his attention upon high-resistance platinum filament lamps, and succeeded in successfully producing a finished article.

The very high cost of the material, however, coupled with the low efficiency of the lamp and the ever-present danger of an accidental burn-out due to pressure rises, were against the platinum filament lamp from the commencement, and prevented it from ever becoming a commercial success.

In 1879, however, he made the discovery that filaments made of carbonised bamboo yielded a practical lamp, while Swan, having found that the use of low-resistance carbon lamps was a step in the right direction, worked up to high-resistance ones, and arrived at practically the same result as Edison at the same time.

Carbon having been proved a suitable substance for filament manufacture, then held the field until comparatively recent times, and manufacturers appeared to take it for granted that a departure from carbon was an impossibility.

This may have been due to the fact that platinum, a metal apparently held in awe and reverence by all early electricians, having been proved a failure, the use of any other metal was looked upon as a ridiculous proceeding, although, perhaps, the great difficulty attending refractory metal experiments at that time may have had something to do with it.

The early carbon lamps were all practically what would now be

called low-pressure lamps—70 to 100 volts being the most usual ratings. The manufacturing processes at the time did not lend themselves to the production of thin, high-resistance filaments, and therefore, of high-voltage lamps, and it was not until the method of producing filaments by squirting a solution of cellulose in zinc chloride had proved itself a success that manufacturers were able to satisfy the demands of users for high-voltage lamps.

Manufacture of Carbon Filaments.—The carbon filaments in use at the present day are manufactured by first dissolving cellulose in a solution of zinc chloride until a viscous solution or syrup is obtained. The cellulose, of course, contains the necessary carbon, and the rest of the process consists in the elimination of the other matter, and the refining of the remaining carbon filament.

The syrup, having been prepared, is purified and then squirted through a die of the requisite diameter, and emerges in the form of a thin thread which is allowed to harden, generally in alcohol, and afterwards wound on drums to dry.

The thread is then cut to the required length, and wrapped on charcoal holders of the correct shape, and finally carbonised by heating in crucibles packed with graphite.

The necessary temperature is about 2000° C., the carbon thereby being rendered exceedingly durable, of increased conductivity and decreased acclusion.

The filaments, however, are far from uniform, and if mounted and placed on circuit would appear patchy, the thinner portions glowing more than the thicker ones of less resistance. It is necessary to reduce the filament to one of uniform diameter, and to perform this operation the flashing process is resorted to.

Flashing.—The filaments after carbonisation are raised to incandescence by electrical means while in an atmosphere of hydrocarbon vapour.

The temperature attained is such that the vapour is decomposed into its constituents hydrogen and carbon, the latter being deposited on the surface of the filament, which is thus provided with a hard coating, and rendered of uniform diameter and resistance throughout.

Flashing further increases the efficiency, and improves the lasting properties of the filament.

Carbon lends itself admirably to the construction of strong filaments.

Its specific resistance, compared with that of metals, is very high, being of the order of 0·004 ohm per centimetre cube, which means that for a given resistance, the length of the filament may

be short, and the diameter fairly large, a strong construction resulting.

By reason of their strength carbon lamps for a long time were recommended for exposed positions or positions of danger from a lamp point of view.

For traction purposes, and for such places as cellars and warehouses, carbon lamps were until quite recent times to be recommended, but as will be seen later, the newest metal lamps are sufficiently strong to warrant their use in all places where economy permits.

Occasionally, however, the cost of the lamp is the main item, the hours of actual service being so few that the energy cost is insignificant. A country hall, for example, may be used perhaps for a few hours monthly, in which case it may be cheaper to instal carbon lamps.

Temperature Coefficient.—A point to be noted when dealing with carbon is the fact that its temperature coefficient is negative.

Unlike the metals the resistance of carbon decreases on the application of heat. The resistance of a carbon filament is thus a maximum when the lamp is not on circuit and it decreases as soon as the pressure is applied.

Over-running is, therefore, attended with the danger of a burn-out, as the hotter the filament becomes the lower will be its resistance, the current consequently tending to continually increase.

Vacuum Operation.—Carbon oxidises readily when heated in the air or in an atmosphere containing oxygen, and therefore to protect the filament from oxidation and destruction, it must be operated in a vacuum, or, in other words, the air must be exhausted from the glass bulb in which the filament is mounted.

A good vacuum is of the highest importance, as contact with gas results in conduction and convection taking place with a lowered overall efficiency, the gain, however, being decreased somewhat by reason of the fact that vacuum operation tends to increase vaporisation of the filament with subsequent obscuring of the bulb.

The carbon filament changes in character as vaporisation proceeds, the small particles that leave the surface causing the latter to lose its smooth appearance, and to assume an exterior composed of many projections and depressions.

In consequence of this the radiation surface is considerably increased, which means that for equal energy expenditure a lower temperature of filament and decreased efficiency will result, a further decrease being brought about by the volatilised carbon

depositing on the comparatively cool surface of the bulb, which blackens and acts as an absorbing screen.

The efficiency, as will be shown later, can be considerably increased by even a small temperature rise, or, what amounts to the same thing, by over-running, and the question that naturally arises is what is the limiting temperature of operation?

It has been shown above that, owing to being continually subjected to a high operating temperature, the filament gradually changes, losing its hard smooth surface and becoming possessed of one more or less rough. The filament becomes weaker owing to the loss of material which, being deposited on the bulb surface, forms a light-absorbing screen. All these processes of destruction are very considerably hastened by still higher temperature.

It is true that at the same time the efficiency is increased, but this is clearly at the expense of the lamp whose life is shortened by the vaporisation taking place.

The operating temperature must then be such that the greatest output is obtained with the least cost for energy and lamp renewals, and must be found for each particular variety of filament, being about 1800° C. for the average carbon filament.

Filament Mounting.—As regards the actual mounting of the filament, connection is first made to its ends by means of two small pieces of platinum wire, a joint being temporarily made between the filament and metal and then completed by electrically depositing carbon on to it from benzine. This process usually precedes the flashing process, and after the latter has taken place the filament is ready to be mounted in the glass bulb.

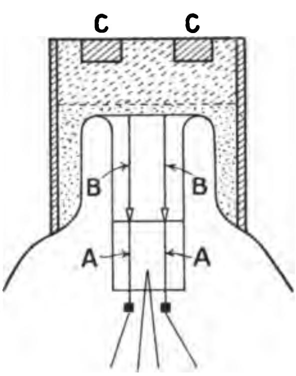

FIG. 20.

The platinum wires are fused through the glass support as shown at A in Fig. 20, platinum, in spite of its high price, being used of necessity for this operation since it is the only known metal whose coefficient of expansion equals that of glass.

The platinum wires are then attached to two copper wires, B, B, which are in turn connected to two contact plates, C, C, embedded in the cap, the inside of the latter being filled with some sort

of glassy slag of good insulating properties, but non-hygroscopic.

Vacuum Production.—The bulb is now exhausted by means of air, and finally mercury pumps, the vacuum being tested by high pressure coils, and when sufficiently good the bulb is sealed off with a blowpipe, and the lamp is ready for testing.

Gem Filaments.—Gem filaments are special types of carbon filaments. They are prepared in the ordinary way, but subjected to additional heating, both before and after the flashing process.

This treatment, besides removing impurities and reducing the filament's acclusion, or gas-retaining powers, appears to modify its construction, imparting to it properties similar to some of those possessed by the metals employed in lamp manufacture.

Metal Lamps.—To achieve success in filament form a metal must possess several very important properties. To permit of its continuous running at very high temperature it must be refractory, and it has long been known that many metals can withstand much higher temperature than carbon without excessive disintegration taking place.

Carbon is the most refractory material known, and what may be called its melting point, or the temperature in the arc crater, is given by various authorities as varying between 3600–4000° C.

Yet, in spite of this fact, carbon, in comparison with such metals as tungsten and tantalum, is an unsatisfactory material from a filament point of view. The metals have a much lower melting point than the carbon, but possibly by reason of their high atomic weights they can be operated continuously at a higher temperature, their rate of evaporation from the solid state being much lower.

The temperature limit of the filament is then not so much the melting point as the temperature at which evaporation is such that the life of the filament is unduly shortened.

Again, to produce filaments of reasonable length and of sufficient diameter to afford strength to withstand vibration, handling, etc., the resistance constants of the material must be satisfactory. Here it may be remarked that the metals have one great point in their favour, and that is, that they possess positive temperature coefficients.

An increase in temperature produces an increase in resistance, the current tending to remain constant, and automatic regulation practically taking place. It is possible to run a metal filament lamp at twice its normal voltage for a short time if the latter be raised gradually from normal.

Metal filament lamps on a varying voltage circuit, the variations

being other than mere voltage flickers, will yield a much steadier output than will carbon ones on the same circuit, for the changes in the filament resistance of the former will be such as to damp out current fluctuations to a great extent, while as regards the latter an increased temperature results in a decreased resistance and immediate current increase.

At the present time the metals employed in the manufacture of lamp filaments to the practical exclusion of all others are tantalum and tungsten.

Tantalum.—Tantalum is an exceedingly hard metal of great strength, ductility, and conductivity. The wire is prepared by melting tantalum in an electric furnace, heating the ingots red, hammering them into sheets and then drawing the sheet down into wire.

The melting point is stated to be about 2000° C., while the atomic weight is 183, permitting of high temperature operation without undue evaporation of the filament.

The specific resistance of tantalum when cold is some ten times that of copper, namely 15·5 microhms per centimetre cube, and this increases to 83 microhms at the running temperature.

Compared with that of carbon the specific resistance is seen to be exceedingly low, and this means that filaments of great length and small diameter are a necessity, a 25 C.-P. lamp designed to run on a 110 volt circuit, for instance, requiring a filament over 2 feet, or 25 inches to be exact, in length, the diameter not exceeding 0·05 millimetre or about 0·002 inch.

It is a triumph to draw wires down to this exceedingly small diameter and yet be able to handle them sufficiently to mount them without breakage.

From information obtained from the makers, the method of doing this is as follows: The metal is first formed into fairly thin rods, and then drawn through diamond dies of decreasing diameter until the required cross-section of filament is obtained. The remainder of the manufacturing process, apart from the fact that the filament has to be wound on supporting arms, by reason of its great length and small diameter, proceeds much in the same manner as does the manufacture of the ordinary carbon lamp, the only difference being that in the case of the metal lamp, a higher vacuum is required and the flashing process is not resorted to.

Tungsten is an exceedingly hard metal with electrical properties similar to those of tantalum, but differs from the latter ductile metal in being very brittle.

In the early days of Tungsten lamps the filaments were made by squirting tungsten powder that had been mixed with some suitable material through a diamond die.

Manufacture of Pressed Filaments.—The early "Osram" or tungsten lamp had filaments prepared by what is known as the paste process, the principle of which consists in preparing, usually from the metal itself in a finely divided form, a paste with a binding agent such as gum. This paste, with a consistency of putty, is then forced through a fine hole in a diamond by a pressure of several tons to the square inch.

The filaments so formed are heated away from air, and are then sufficiently strong to be clamped in holders, in order that they may be subjected to the passage of an electric current which raises them to a high temperature causing the filaments to sinter. The sintering process is carried out in gases which chemically attach all the constituents of the binding agent, the result being that a filament of pure metal is obtained.

The diameter of the filament is exceedingly small, that of a 25-C.-P. 110 volts lamp not exceeding 0·03 mm. Tungsten filaments so manufactured are elastic but brittle, and require very careful mounting, and a single loop of metal for each support.

There are many disadvantages of the pressed filament type of lamp, and the problem of drawing down the metal tungsten and so producing a drawn wire tungsten filament in one continuous length has only recently been solved.

Drawn Tungsten Wire.—It was known that the tungsten filament, brittle at ordinary temperature, became soft and flexible at the operating temperature of the lamp, but that it lost this property as soon as it had cooled down again. Coolidge discovered that it had the property of softening, even below red heat, and he was able to work tungsten at relatively low temperatures. He further discovered a process by which it is possible to render tungsten ductile by a mechanical treatment of the material in the heated state, and to also give it a permanent ductility while in the cold state. According to this process pure tungsten powder is pressed into rods, then rendered coherent by heating, hammered while hot, and finally drawn out into wire through diamond dies.

Lamps manufactured from such wire show not only the great economy, long life, and constancy in candle-power of the old tungsten lamps, together with automatic regulation, but are equally strong, being one continuous length of drawn wire, with the carbon lamp.

After the discovery of this process a further important success

was obtained, as it was found possible to draw down filaments of even finer diameters, so that lamps are now obtainable of even 10 C.P. for pressures of 200 volts and over. In the case of the latter lamp, the filament is no greater than 0·012 mm. in diameter, a marvellous result when the properties of the material are taken into account.

The mounting of the wire now is a very simple process. It is wound in a continuous length, in a zigzag manner, round a glass carrier, as shown in Fig. 21, and which carries, at the top and bottom, a star-shaped carrier consisting of a number of metal supports.

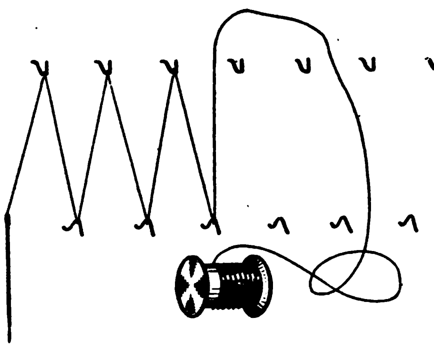

FIG. 21.

One carrier consists of strong, stiff material, whereas the other is made of very fine refractory wires, molybdenum being used in the Osram lamps of the present day. These fine supports act as springs, and keep the filament in its original position, no matter at what angle the lamp is supported.

The importance of this feature will be rendered evident when the large amount of sag resulting, when many of the cheaper metal lamps are used, is observed. The filament, in some cases, sags so much as to touch the glass, breakage resulting, or even if this is avoided, the appearance of the lamp suffers considerably by the misplacement of the wire.

The drawn wire lamps are completed, as far as sealing in and exhaustion are concerned, in much the same way as are the pressed filament lamps previously described.

The metal wire lamp, as now manufactured, means a success over all other types of electric lamp, and is, to quote Dr. Geisel, definitely superior even to gas lighting.

It has been the means of introducing extension of electric lighting, and of popularising electricity generally, and as such has rendered great service to the whole electrical industry.

Users of such lamps as the Mazda, Osram, Wotan, to name only the best known of the tungsten drawn filament makes, need

have no fear of the fragility of the filament. The pressed filament lamps almost superseded all other makes by reason of their great economy, and this, in spite of the fact that the filaments were brittle and fragile, and the invention of the tungsten wire finally established the superiority of this form of incandescent lamp over all others.

CHAPTER VII

CHARACTERISTICS OF INCANDESCENT LAMPS

THE introduction of the drawn wire tungsten metal filament is undoubtedly the most important advance that has yet been made in the production of incandescent electric lamps. The lamp with the squirted or pressed metal filament created quite a sensation when it was introduced, as it was a wonderful improvement over the carbon lamp, absorbing but little more than 25 per cent. of the power absorbed by the latter, yielding a whiter light, or a light more closely resembling daylight, and further, having a much longer life than its rival.

The disadvantages attending the use of such lamps were, and still are, made much of, and are occasioned by the fact that the filaments, by reason of their construction, are fragile and delicate, and so render themselves liable to easy breakage when handling, fixing, or cleaning, is undertaken.

These drawbacks, however, have been completely overcome by the production of the drawn wire filament which, while retaining all the good points of the pressed filaments as regards life, efficiency, colour of light and regulation, is, in addition, strong enough to withstand ordinary treatment such as, without special instructions are issued, is generally meted out to all goods in transit.

The filament being practically a new departure, it becomes of interest to study carefully life and efficiency tests that have been carried out on numerous examples, and by the courtesy of the *Electrical Review*, the author is enabled to reproduce results of tests published by him in a paper appearing in the issue of that journal, dated September 20, 1912.

Life Tests.—In life tests the lamps to be tested are arranged in a pendant position, and the rated voltage maintained absolutely constant by regulating apparatus, for a period of not less than 1000 hours.

This period is now very often extended, and quite recently the

Osram Company published the result of life tests which had been continued for 2000 hours.

It is essential that the voltage be maintained constant during the test, as the life of a lamp is greatly reduced if the pressure is subject to variations.

Carbon lamps especially will blacken much more quickly on a varying voltage circuit than they will do if the pressure is maintained constant.

The reason for this is that when the voltage increases the temperature also increases, and the rate at which evaporation of the filament proceeds is hastened.

In almost all cases the useful life of the lamp is ended, or the "smashing point" reached when the candle-power has fallen 20 per cent. of the original rated value, and it cannot be too strongly urged upon users of incandescent lamps that it pays in the end to replace lamps at this point. The cost of the lamp in no way compares with the increased energy cost necessary to obtain adequate lighting of the premises in question.

During a life test numerous candle-power and power-consumption measurements should be taken at regular intervals, care being taken to ensure that the correct voltage is accurately maintained. Against such tests can be urged the great cost and prolonged period of waiting for final results, while the necessary attention is no small item. It is on this account that an estimate of a lamp's behaviour is sometimes arrived at by over-running it, but it is doubtful if such a method is of value. The characteristics of a certain type of lamp should be obtained, as will be explained later, and it is then sufficient to test a batch of lamps chosen haphazard as occasion demands.

The candle-power having been obtained, and the power consumption in watts noted, the so-called efficiency of the lamp can then be expressed in watts per candle. It is customary to rate lamps in terms of their mean horizontal candle-power, so that the efficiency will necessarily be expressed in watts per mean horizontal candle-power.

For example, a metal lamp, with a mean horizontal candle-power of 25, absorbing 35 watts, would have an efficiency of 1·4 watts per candle, while a carbon lamp of 16 mean horizontal candle-power, absorbing 64 watts, would be rated at 4 watts per candle.

It will be noted that the higher the efficiency the poorer the lamp—a contradiction of terms surely. Inefficiency or specific consumption would more accurately express the performance, and confusion no doubt would thereby be avoided.

Life tests are valuable as affording a general indication of the life performance of a certain type of lamp, but too much value must not be placed on the results of individual tests.

Lamp testing, undertaken on a small scale, is apt to prove very misleading, and as a result of such tests incorrect conclusions are frequently drawn. In all lamp tests, and indeed in all cases of comparison, whether lamps are immediately concerned or not, a sufficient number of tests should be undertaken to ensure a true average result being arrived at. If a single lamp is tested, it may be a very good one or quite the reverse, and the result in either case would be misleading, whereas the average of the tests made on a large batch of lamps would supply a good deal of useful information.

Contractors frequently base their opinions on single tests, and the author has in mind quite a well-known engineer who insisted on the installation of a proved poor lamp, because one particular specimen, installed over his desk, had run for close on 2000 hours. That it had blackened considerably during this period seemed a minor detail to him, although obviously the efficiency had been considerably impaired.

When there are so many good and reliable lamps available, the manufacturers of which are only too pleased to furnish results of exhaustive tests, it seems a pity that such stupidity is allowed to sow prejudice and work a possible injury to the electrical industry.

Life tests indicate that the candle-power of lamps varies considerably during the first 50 hours or so of the run, and this interval of time constitutes a period of instability.

A filament, when new, exhibits a surface that has a metallic lustre, but which under the microscope appears rough, and in the case of tantalum presents a porous appearance.

During the initial stages of the test the structure of the filament may change slightly, leading to a decreased resistance, and an increased current with increase in candle-power. It is quite possible that the vacuum may be improved, and an improved vacuum by reducing conduction and convection losses would give rise to an increased efficiency.

Gradual evaporation of the filament, however, due to its continued operation at a high temperature sets in almost immediately, resulting in a change taking place in the filament surface.

Instead of presenting a smooth surface the evaporation taking place leads to one which is pitted and crinkled in an irregular manner and the radiation area being increased, the lowered temperature results in a decreased lamp efficiency.

As previously mentioned, the vaporised filament deposits on the comparatively cool interior of the glass bulb, the resulting layer absorbing a considerable quantity of light during the later stages of the run.

In this connection it must be again emphasised that lamps which blacken rapidly are unfit for use in view of the increased energy cost for equal light outputs, although it must be stated that good present-day lamps do not blacken to any appreciable extent after 1000 hours' run, the exceptions merely indicating the presence of a poor vacuum or the presence of water vapour.

The result of these ageing processes is indicated by a gradual decrease in the candle-power of the lamp, and a proportionate increase in the consumption, or watts per candle.

The filament further undergoes structural changes and loses some of its mechanical strength, the result being that, especially with the pressed filament type, a sudden blow may shatter it.

Care must be exercised when lamps are cleaned, and, if it is possible to avoid it, lamps should never be removed from their sockets after once switching them on to the circuit. Haphazard changing of lamps, the removal of one to replace another in a different part of a building, incorrect pairing, if series running is adopted, and many other causes lead to innumerable breakages, and harsh words being said about metal filament lamps. If large numbers of lamps are used, it will be found a very good plan to appoint some one to take complete charge of the lamps themselves, and to issue orders to the effect that no unauthorised person must interfere in any way with the installation.

In schools and offices especially the lamps receive very rough treatment at the hands of scholars or clerks as the case may be. Lamps are changed and replaced, and if series running is the system in use a 25 C.P. is frequently paired with a 16 C.P. lamp, the general result being that much unpleasantness is caused to the agent or manufacturer as well as to the user.

Typical life and efficiency curves are indicated in Fig. 22, and the period of instability is clearly shown.

A study of these curves will make it clear that when the lamp has attained what may be termed its true candle-power, the latter remains fairly constant, in some cases for several hundred hours.

The gradual fall in candle-powder that is noticed when dealing with carbon lamps, and which was also a noticeable feature during the life of metal lamps, is in many cases now not to be observed,[1]

[1] "Proceedings of Institution of Electrical Engineers," Feb., 1907. Paper by D. H. Ogley and H. F. Howorth.

and in this connection it may be noted that the smashing point of metal lamps does not come within the 1000 hours' limit, and in general is determined by the rupture of the filament.

The curves shown in Fig. 22 further indicate that the lamp efficiencies remain practically constant during the greater portion of the life tests. In the case of the Mazda lamps the candle-power remained almost the same for 600 hours, while published tests of

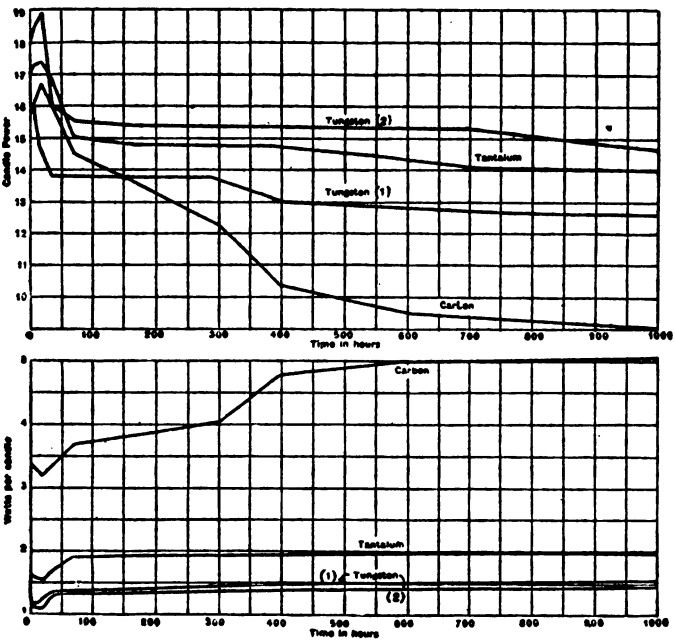

FIG. 22.

Osram lamps indicate that similar results have been obtained with lamps of that particular variety.

From these results it wou'd appear that aged tungsten lamps would serve admirably as photometric substandards, it being necessary, of course, to check them at intervals against a recognised standard.

Before leaving the subject of life tests it should be clearly understood that the curves shown are not chance curves, but are the results of tests made on a large number of lamps of every kind ;

that the ones shown do closely resemble the individual curves indicates that great uniformity at the present day attends lamp manufacture.

Voltage and Candle-Power Variation.—It has long been known that for given pressure changes the percentage variation in the candle-power of a carbon lamp exceeded that of a metal lamp of equal rating, and the question naturally arises as to the extent of the variation.

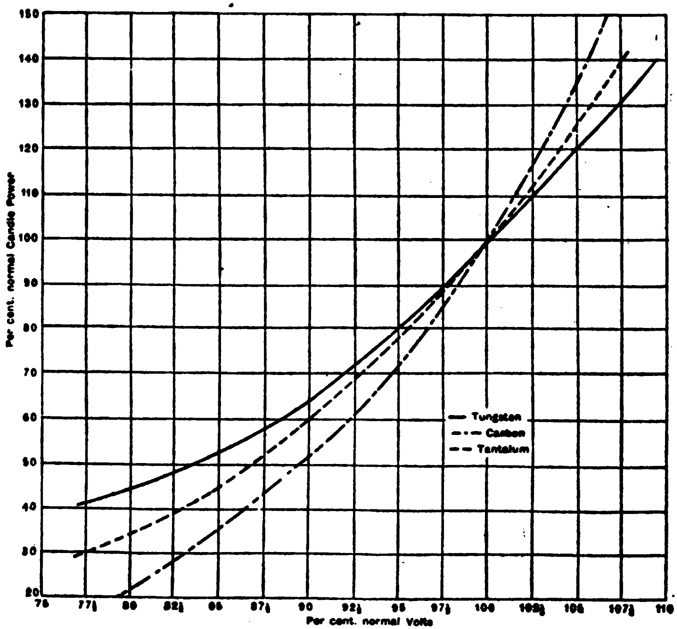

FIG. 23.—Relationship between Candle-Power and Volts.

In making such a test the lamp should be arranged in series with a resistance of such a value that considerable variation in lamp pressure is possible.

The candle-power may then be accurately measured in the usual manner and the results exhibited by means of curves, showing the relationship between candle-power and applied pressure.

Several curves obtained in this manner are indicated in Fig. 23, and it will be at once apparent that the curve for the carbon lamp is much steeper than either the tantalum or tungsten lamp curves.

In the paper previously referred to the voltage index obtained for the various types was as follows—

Lamp.	Volts Index.
Tungsten	3·5–4·1
Tantalum	4·1–4·3
Carbon	6·7–7

and the superiority of the metal lamp, as regards a permanent change in voltage, is made clear.

Since relatively slight reductions in pressure produce large decreases in candle-power the importance of close regulation is apparent, while although on the other hand a correspondingly great increase in candle-power results on an increase in pressure, the rapid deterioration of the filament renders the process a costly and unwarranted one.

It is evident, as before stated, that the pressure at which the lamp is to be continually operated must be so chosen that the ratio of the total light produced to the cost of energy, plus cost of lamp, must be a maximum, and this requires very careful selection of resistances and pressures.

Current and Candle-Power Variations.—Other useful relationships are those between candle-power and current, and power consumed and impressed voltage.

In Fig. 24 is shown the relationship existing between candle-power and current, and in this respect it will be observed that the carbon lamp is as good, if not better than any metal filament one.

The current index obtained for the various types was as follows :—

Lamp.	Current Index.
Tantalum	5·5–5·8
Tungsten	5·0–6·5
Carbon	5·2–5·4

and it will be seen that the variation amongst the tungsten filaments is very considerable, this probably being accounted for by the fact that the manufacturing processes differ slightly.

A study of these figures makes it clear that it is more important, from a fixed intensity point of view, to maintain the current constant, leaving the pressure to take care of itself. For instance, in using glow lamps as sub-standards in photometric work, the current should be maintained constant by means of potentiometer measurements, a special battery being very useful in this connection.

Power Characteristics.—The power characteristic, or the relationship between power and impressed voltage, was first

analysed by Steinmetz, who, on the results of tests made on a single tungsten lamp, stated that the power consumption varied as the 1·6th power of the impressed voltage.

The lamp follows the same law as the hysteresis loss in iron,

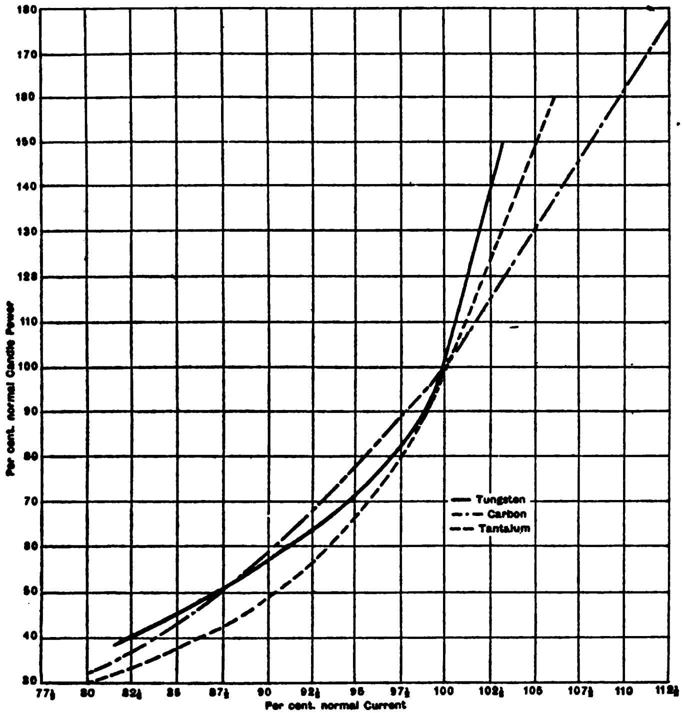

FIG. 24.—Candle-Power and Current.

the latter increasing as the 1·6th power of the induction, or stated in symbols

$$(1)\ W \propto V^{1 \cdot 6}$$

$$(2)\ W \propto B^{1 \cdot 6}$$

where (1) refers to the lamp, W being the power in watts, and V the pressure in volts, and (2) refers to the iron, W being the power in watts, and B the induction.

This law may be expressed as an equality

$$W = KV^{1 \cdot 6}$$

K being a constant.

The results of tests made on four modern lamps are as follows :—

LAMP I.

Test.	Candle-Power.	Volts.	Ampères.	Watts.	Watts calculated.	Difference.
1	8·2	90	0·15	13·5	13·49	—
2	10·23	95	0·155	14·7	14·71	—
3	12·6	100	0·16	16·0	15·85	−0·9 %
4	14·24	105	0·166	17·4	17·28	−0·7 %
5	16·7	110	0·169	18·6	18·6	—
6	19·97	115	0·174	20·0	19·97	—
7	24·46	120	0·179	21·5	21·38	−0·5 %

Power characteristic: watts = $0·01008 \text{ volt}^{1·6}$.

LAMP II.

Test.	Candle-Power.	Volts.	Ampères.	Watts.	Watts calculated.	Difference.
1	10·1	100	0·14	14·0	13·84	−1·1 %
2	11·6	105	0·144	15·1	14·96	−0·9 %
3	14·5	110	0·147	16·2	16·12	−0·5 %
4	16·18	115	0·15	17·3	17·3	—
5	19·7	120	0·154	18·5	18·52	+0·1 %

Power characteristic: watts = $0·00873 \text{ volt}^{1·6}$.

LAMP III.

Test.	Candle-Power.	Volts.	Ampères.	Watts.	Watts calculated.	Difference.
1	5·58	85	0·17	14·4	14.47	+0·5 %
2	7·1	90	0·178	16·0	15·87	−0·8 %
3	9·07	95	0·182	17·3	17·3	—
4	11·2	100	0 188	18·8	18·78	−0·1 %
5	13·46	105	0·194	20·4	20·31	−0·4 %
6	16·5	110	0·2	22·0	21·9	−0·4 %
7	19·56	115	0·205	23·6	23·5	−0·4 %
8	22·0	120	0·208	25·0	25·12	+0·4 %

Power characteristic: watts = $0·01185 \text{ volt}^{1·6}$.

LAMP IV.

Test.	Candle-Power.	Volts.	Ampères.	Watts.	Watts calculated.	Difference.
1	7·43	90	0·15	13·5	13·49	—
2	8·8	95	0·154	14·6	14·71	+0·7 %
3	11·26	100	0·16	16·0	15·85	−0·9 %
4	12·5	105	0·163	17·1	17·28	+1·0 %
5	15·5	110	0·168	18·5	18·61	+0·6 %
6	18·6	115	0·174	20·0	19·97	−0·15 %
7	22·0	120	0·179	21·5	21·38	−0·5 %

Power characteristic: watts = $0·01008 \text{ volt}^{1·6}$.

The calculated watts were obtained in all cases by making use of the equation, watts = K × $\text{volts}^{1·6}$, and it is interesting to note that the greatest variation is only of the nature of 1 per cent.

A frequent determination of the constant K might serve as a check during manufacture, and the creeping in of errors be thus avoided.

In Fig. 25 the relationships are indicated graphically, the observed watts being also shown, and are seen to all lie practically on the curves.

Resistance Changes.—It is interesting to make frequent resistance measurements during the progress of a life test to ascertain if changes are taking place in the filament.

The results of some such tests are shown in Figs. 26, 27, 28, the resistances being plotted as ordinates and the duration of the test in hours as abscissæ.

From these curves it is clear that both drawn and pressed filaments become crystalline after use, and as regards this particular condition no difference in strength is to be found between the two.

It must not be supposed, however, that the drawn filament is as fragile as the pressed one merely because it crystallises. This view has been expressed, but is undoubtedly a wrong one, as there are many other points to consider before pronouncing a verdict.

Strength of Drawn Filaments.—The strength of a drawn filament does not depend solely upon the ductility of the metal, but largely upon the method of winding and mounting which the drawn filament from its very nature permits.

The whole filament when mounted is in one continuous piece,

of absolutely uniform cross-section. The wire being drawn, and not pressed adds this feature of strength to the arrangement, while

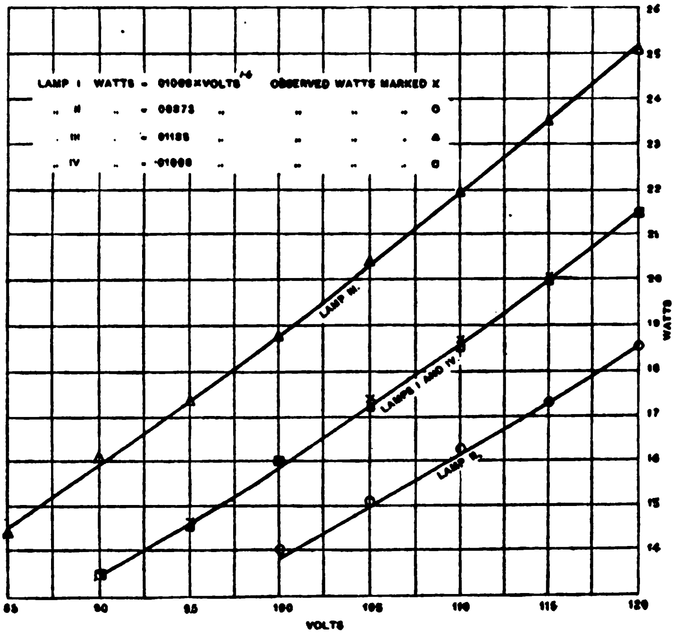

FIG. 25.

further, the method of support is a point to which great attention must be paid.

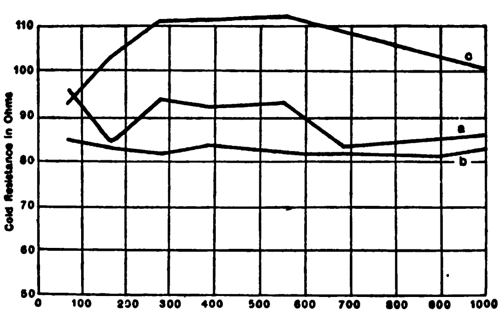

FIG. 26.—Resistance Time Curve, Drawn Filament Lamp.

The pressed filaments are attached to each other by welds or joints, and held rigidly in position as shown in Fig. 29.

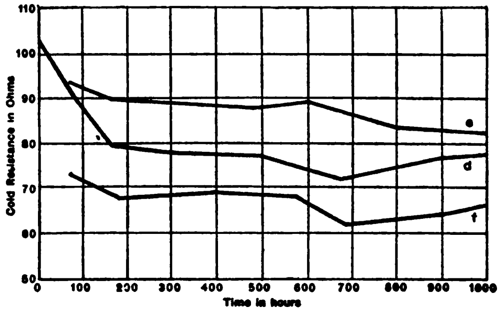

FIG. 27.—Resistance Time Curve, Pressed Filament Lamp.

It is impossible to assemble several of these limbs to form a complete filament and yet be sure that the resistance and cross-

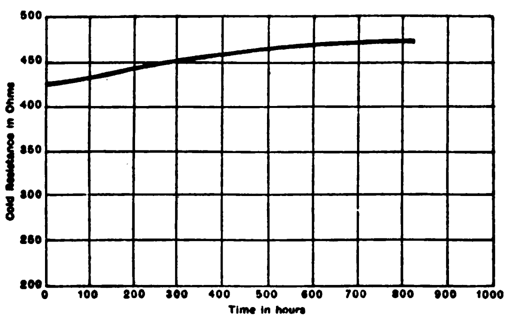

FIG. 28.—Resistance Time Curve, Carbon Lamp.

section of each is the same. There is no "give" in the arrangement, the structure being an exceedingly fragile one.

The drawn wire filaments are mounted on flexible supports, any sag being taken up gently by the spring of the retaining arm, the general result being that the drawn wire lamp at any period of its life is much stronger than one with a pressed filament.

Further, the drawn filaments crystallise more slowly, and in this respect are stronger than the pressed ones during the initial stages of their life.

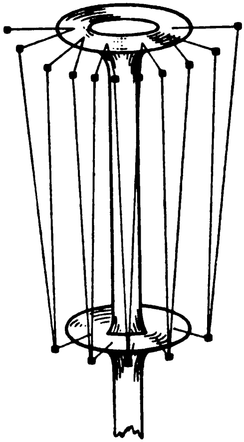

FIG. 29.

A special machine has been in use for some time in America, testing the strength of filaments, the following results being obtained :—

Tensile tests made on both drawn and pressed filaments at various stages of life indicated a strength of from 20,000–60,000 lbs. per square inch, which is, doubtless, much in excess of that required for lamp filaments. The drawn wire was much stronger in all sizes.

The drawn wire further showed 100 per cent. greater deflection for equal loads, the breaking load in bending being also greater.

These results prove conclusively that the drawn filament is much stronger in every way than the pressed filament, and all users should insist on drawn wire lamps being supplied when an electric installation is contemplated.

CHAPTER VIII

THE EYE AND THE PRINCIPLES OF VISION

GENERALLY speaking, in order that the eye may exercise its functions correctly at all times, artificial lighting is relied upon whenever daylight fails, and the question arises as to the effect on the eye of the brilliant light sources so much in use at the present time.

Great strides have been made in comparatively recent times as regards the intrinsic brilliancy and candle-power of luminous bodies, so much so that the eye has had no time to become what may be called educated up to the new conditions. The eye remains in practically the same state as it was when the candle was the principal luminant employed, and at the present time is just as unfit as it was then to regard a naked light of high intrinsic brilliancy.

Until comparatively recent times no branch of engineering had been more neglected than that dealing with scientific illumination, the early lighting engineers apparently having one object only in view, that being to obtain the greatest possible output with the least energy consumption, the eye calling for no thought whatever beyond that of impressing it with the display.

Consider in this connection the effect of a single glimpse, accidental or otherwise, of the sun on the eye.

The nerves of the latter are injured to such an extent that distinct vision for some considerable time afterwards is an impossibility, and it is on record that owing to the destruction of the optic nerve through such a cause blindness has resulted.

Some such effect, though in lesser degree, is produced every time an incandescent lamp with a clear bulb is regarded, and although it is only recently that such fact appears to have called for comment, one has merely to read in medical reports of the increasing number of cases of eye trouble, especially among children, to realise that some new cause is at work causing eyesight

destruction, and without the slightest doubt unscientific lighting is in great part to blame.

To appreciate the question a study of the eye is essential.

The Human Eye.—The human eye may be regarded from an optical point of view as a simple camera in which the sensitive plate is replaced by the retina, a collection of nerve terminals sensitive to light.

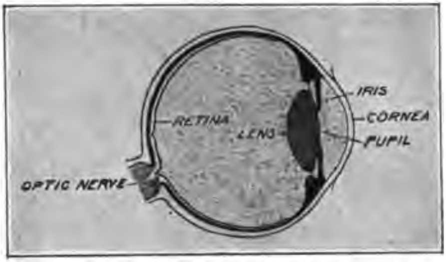

FIG. 30.—The Human Eye.

As shown in Fig. 30, the front of the eye is occupied by a double convex lens of elastic material suspended by a flexible muscle, by whose movements the focus of the lens is adjusted to the distance of the objects in view.

The lens further divides the eye into two parts, the posterior chamber filled with the vitreous humour, and the anterior chamber which contains a watery liquid called the aqueous humour, and which chamber is bounded in front by a tough transparent substance called the cornea.

In front of the lens is the iris, a muscular covering with a circular opening, which closes in a strongly illuminated field and opens when the illumination is decreased, as shown in Figs. 31 and 32, the tendency being to admit to the eye the correct amount of light to render vision clear under all conditions.

Formation of Image.—Images of external objects are formed upon the retina of the eye, partly owing to the refractions that take place through the humours mentioned, but mainly owing to the action of the lens itself.

If an object viewed be excessively bright an intense image will be formed on the retina resulting in the nerves being injured for some time, and if such images are allowed to be frequently formed permanent injury may be the result.

All readers will, no doubt, be familiar with the injury resulting from the observation of a clear bulb incandescent lamp, while if an uninterrupted view of an arc crater is obtained by any means the eye will be rendered practically useless for some considerable time.

The pupil, as before stated, always contracts when the field of view is excessively illuminated, in the effort to protect the retina by reducing the amount of light entering the eye. Unfortunately the iris is not instantaneous in its action, the painful sensation caused by entering a brilliantly lighted room after being in a dark one for some little time bearing evidence to this fact. The pupil would be fully extended in the dark, and on entering the other room an excessive amount of light would enter the eye before the iris had time to act, the excessive images produced causing temporary injury to the eye nerves, the observer being what may be termed "dazzled" for the time being.

Cyclists and others who have occasion to use country roads at night, will frequently experience great discomfort due to the head lights of motor-cars excessively illuminating the field of view.

Fig. 31.—Pupil contracted to shut out excessive light.

Fig. 32.—Pupil expanded to admit of as much light as possible.

From these and other considerations it is clear that excessive illumination of objects viewed is undesirable if eye-strain is to be avoided, while further, all luminous bodies of high intrinsic brilliancy must be so placed as to be out of the field of view completely.

Clear bulb metal and carbon filament lamps have been shown previously to be sources of high intrinsic brilliancy, and as such these should be installed so that a clear view of the filament is an impossibility, although how little this fact is appreciated may be gathered from a glance at the average shop or house installation.

In nine cases out of every ten practically, it will be found that exposed units are in the line of vision, so much so that the eye becomes strained in the effort to clearly appreciate less bright objects.

On the other hand, insufficient brightness is equally undesirable.

In this case it becomes an effort to distinguish things in detail and eye-strain results.

Reading by failing daylight is a frequent cause of mischief, but it is a habit to which practically everybody is addicted.

In every case the illumination should be such that there is no effort to do the work desired, and no strain should result on its completion.

Direction of Light.—Careful attention should always be paid to the direction of light, as by nature the eye has become used to light from the sun, that is, to light from a source not in the field of view.

The eye-lids, etc., protect the eye from the entrance of direct light from the sun, but from the entrance of light from the great bulk of present-day illuminants there is no protection whatever afforded.

In this connection it then becomes evident, as previously stated, that sources of illumination should not be within the direct line of vision. This applies particularly to school-lighting, as it is in their school days that children are in the most easily influenced stage of their development, bad lighting at their age being especially prejudicial.

Yet in almost all schools and in most public places, with the exception of the comparatively new ones, exposed light-sources will be found, and are a constant source of danger to the eyes, the trouble being augmented by the fact that the tendency of the age is towards units of still greater candle-power and increased intrinsic brilliancies.

The normal eye can regard with equanimity a source whose intrinsic brilliancy does not exceed, say, 5 candle-power per square inch. An ordinary candle placed within the line of vision will not produce any harmful effect.

Consider then the result of placing lamps whose intrinsic brilliancy approaches 1000 in the direct line of vision. The effect on the nerves of the eye must be appalling, and yet such units are still being installed.

The question then naturally arises as to the disposition of the light units to avoid injury to the eye.

If, owing to existing conditions, it is found impossible to place them out of direct view, a diffusing medium should be used to reduce the brightness of the surface. The lamps may be frosted, or use made of globes, as will be shown in a later chapter.

Critics may urge loss of efficiency, but in view of the high efficiency of the present-day illuminants, the loss of some part

of the available energy is to be preferred to the ruin of eyesight.

Further, the lamps may be placed at such a height that only an occasional glimpse of them is possible, but adequate shading is to be preferred if the direct system is in use.

The inverted or indirect system has much to commend it, the light being thrown on to the ceiling, which latter reflects by diffuse reflection, the source itself being completely out of view.

Steadiness of Light.—A point on which too much stress cannot be laid applies to the steadiness of the light supply. If the source is varying in intensity the iris can no longer adjust itself sufficiently quickly to protect the retina, which becomes strained in the effort to maintain clear vision in the varying field.

Flickering gas jets are sources of much trouble, and in this connection it may be mentioned that metal filament lamps, owing to the low specific heat of the metal, respond much more readily to momentary changes in pressure than do carbon ones.

Their intensity will then vary more on a circuit in which the pressure is not adequately controlled, or, in other words flickering will be more pronounced, it being clearly understood that momentary pressure changes, and not permanent ones, are meant.

The illuminants employed should yield a spectrum resembling that of daylight as closely as possible. Hygienic considerations require an avoidance of light containing an excess of ultra-violet rays, the mercury vapour lamp, though useful in many ways, being thus unsuitable for average installations.[1]

Perhaps preference should be given to light of a faintly reddish tint, as it makes objects warm and cheerful, and some people for this reason prefer the carbon lamp to the metal lamp, which yields a whiter light.

[1] D. H. Ogley, "School Lighting," *The Educational Times*, Nov., 1912.

CHAPTER IX

LIGHTING SYSTEMS

(1) *The Direct System*

WHEN premises are lighted directly by incandescent lamps, the latter are visible, but, according to the rules laid down in previous chapters, although visible, the lamps should be so placed as to be out of the direct line of vision. Of course, it will be quite possible, whenever the direct system is employed, to observe the sources, if one wishes to do so; but, under normal working conditions, they should be so placed that this is an impossibility.

In this connection it may be mentioned that the sun is a visible source, but is so placed as to be generally out of the direct line of vision, and, as such, no one thinks for a moment of regarding it directly; natural direct lighting in this way affords an example that should be copied by all interested in direct artificial lighting.

The action of the eye, outlined in the previous chapter, should be well understood before direct lighting is attempted, although, if one is to judge by results, the majority of contractors seem never to give even a passing thought to the injury that may be caused by a direct view of powerful lamps.

As a result of some thousands of observations, the author has found that, in practically all cases of direct lighting, the lamps have been so installed, that users, whether they desire it or not, obtain an uninterrupted view of them from almost all positions, the result being that much harm must be done to the eyes. If a clear bulb incandescent lamp be regarded directly, it is impossible for some moments afterwards to distinguish anything clearly. The injury is at once apparent in this case, yet the same thing occurs, though in a lesser degree, every time even a partial glimpse of such an illuminant is obtained. It must be obvious, however, that continued subjection to even such small injuries must result in trouble in the end.

Direction of Light.—The direction of the light should receive careful attention. It has been shown previously that, whenever light falls upon a surface, more or less reflection takes place, and this reflection may be such as to cause injury to the eyes of any one compelled to observe the surface.

Frequently a lamp is so placed that the reflected beam must of necessity enter the eye. This occurs whenever a reader or writer is working with a lamp in front of him, the trouble being aggravated if the paper surface is a glazed one. School children suffer greatly from this cause, and as the direct lighting system is the one generally employed in schools, the disposition of the units is exceedingly important. The light should, if possible, come from over the left shoulder, when the reflected beam can cause no annoyance.

Polished surfaces frequently give rise to an annoying glare, and, when such occurs, the lighting contractor is usually to blame, having, through carelessness or ignorance, placed the light units in incorrect positions.

It must be clear that, if a troublesome glare exists, the reflected beam is entering the eye, and good work under such conditions is an impossibility. By suitably arranging the lamps this could easily be avoided, and, besides an increased output, the work would be accomplished with a minimum of discomfort.

Window Lighting.—To judge from appearances, the average householder, shopkeeper, etc., suspends a lamp, usually a clear-bulb one, and unshaded, in any position where he imagines additional light is required, the result being that generally he defeats the object that he had in view.

The eye is drawn unconsciously towards any bright object—the advertising effect of unusual coloured lamps bearing witness to this fact. This being so, the eye immediately adapts itself to the ruling conditions. Thus, suppose for a moment that one happens to look into a shop window, perhaps with a view to purchase, and further, let the window be exhibited, as shown in Fig. 33, by means of exposed light units of high intrinsic brilliancy, this, it may be remarked, being the favourite method at present in use.

The brightest objects in the window are undoubtedly the lamps, and the eye immediately seeks them out. The result is, that, to protect the retina from the entrance of too great a quantity of light, the pupil closes, and the rest of the objects appear insufficiently bright by comparison. The lamps, not the goods, are seen, and frequently, rather than suffer annoyance, the potential customer departs.

Shopkeepers should remember that in general they are not selling lamps, and these should be conspicuous by their absence from view.

Yet, to realise how little the average incandescent lamp user appreciates the conditions underlying good lighting, it is only necessary to take a glance at the majority of shops in almost any

FIG. 33.—Shop window lighted with exposed light units.

town. Unshaded bulbs are to be seen in practically every window, and trouble and annoyance is caused on looking into any one of them.

Now compare Figs. 34 and 34A with Fig. 33, and notice the vastly improved conditions.

The lamps are now entirely out of the field of view, and, without a distinct effort being made to do so, it is practically impossible to get even a glimpse of them, while the articles shown can be observed under natural conditions without any annoyance being caused by an objectionable glare.

The materials may be fully appreciated, and detail studied. A tone is lent to the place, and frequently the pleasing lighting effect has much to do with the sales.

The system employed is still the direct one, but by proper disposition of the light units perfect lighting has been obtained.

Exposed lamps in the house, factory, or workshop may cause considerable annoyance and possible injury to the eyes.

Thus in Fig. 35, it will be noted that exposed units have been installed directly over the machine shown.

The arrangement is an exceedingly bad one, as the worker

Fig. 34.—Window lighted by concealed lamps.

receives both direct light and also reflected light from the machine in his eyes.

Again, in Fig. 36, a faulty arrangement of dining-table lighting, although a very usual one, it may be remarked, is shown. The lamps are in the line of vision, and it is almost an impossibility to see beyond them.

In a certain Lancashire mill the whole of one large room is lighted by means of 100 C.P. lamps placed close to the ceiling. The machinery reflects the light in all directions, and to add to the discomfort the lamps are all in full view of the workers. Yet, on this being pointed out to the owner, he seemed highly pleased that the effect had been observed, and remarked that his machinery was shown up most excellently.

To avoid the annoyance caused by glaring lamps they may be

installed at such a height that it is practically an impossibility to observe them under normal conditions.

It is, however, much better to avoid excessive heights if possible,

FIG. 34.

and make use of some of the many excellent reflectors that are to be obtained, an increase in efficiency being in this way ensured.

The reflectors employed must be so designed and disposed that the lamp is completely hidden from view, but no fixed rules

can be laid down, the fixtures in general being adapted to the conditions.

In Fig. 37 an example of bad local lighting is afforded. The

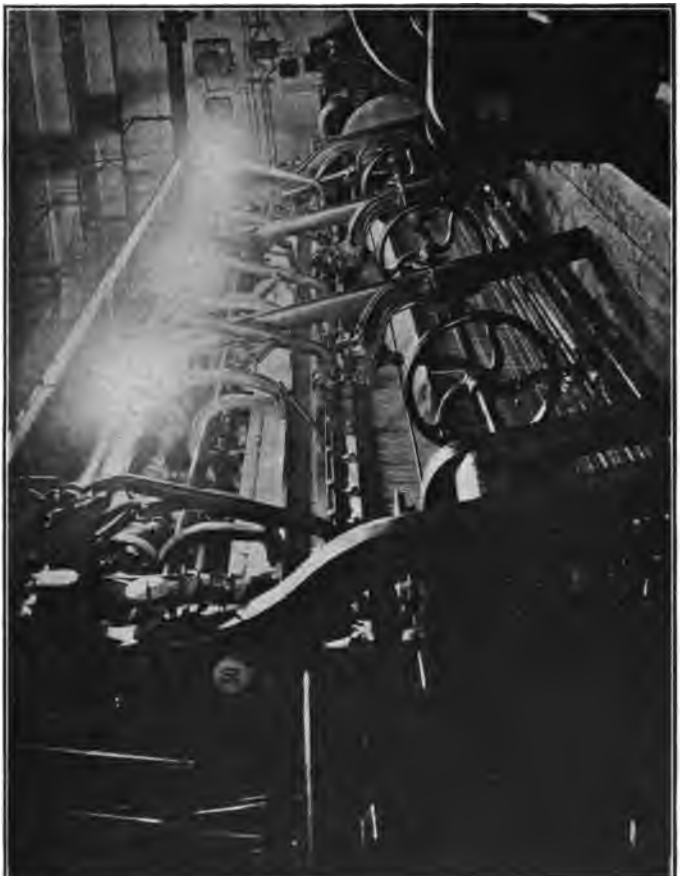

Fig. 35 —Usual lighting of lace machine.

lamp, in spite of the shade, is in full view of the operator, and his eyes are in no condition to cope with detail. The remedy is a simple one, as an alteration in the shade employed would result in the lamp being completely hidden and the light reflected where it is most required—on to the work.

Reflectors in general serve three purposes. They increase the illuminated area and so present to the eye a surface whose brightness is such as to produce no harmful effect; they direct the light in any required direction; while further, if so required, they may be made objects of ornament.

FIG. 36.—Faulty dining-room lighting.

The reflectors may completely surround the lamp, a direct view of which is then an impossibility, as is the case with the holophane bowl pendant illustrated in Fig. 38.

An additional advantage in this case lies in the fact that the material employed is such that an even illumination is obtained, which is very desirable for general purposes. The diffusion is good, and instead of a lamp exhibiting a brilliant filament, there is

presented to the view a globe evenly illuminated, and of such a surface brightness that no annoyance is caused by looking directly at it.

In choosing reflectors care must be taken to ensure that the resulting illumination will be even. Many forms of shades appear

FIG. 37.—Bad local lighting.

patchy, and even allow a view of the filament to be obtained through them. Opal glass gives satisfactory diffusion if the material is not too dense, but it must be remembered that all shades absorb part of the light emitted by the lamp, and faulty judgment may result in the overall efficiency being considerably impaired.

It is well to carefully study the local conditions before deciding

on any particular kind of installation. Some users, for instance, prefer to sacrifice efficiency in order to heighten the artistic effect, when shades that absorb a great deal of the light emitted may be used, the efficiency loss being offset by the gain in ornamentation.

FIG. 38.—Holophane bowl pendant.

In such cases it is wise to ensure that an adequate illumination may be produced if required, and it is usual to instal extra lamps which are only pressed into service when occasion demands.

In a particular case that came under notice a red shade was insisted upon over a dining-room table, a central fitting being the only one the room contained. The illumination of the table is quite satisfactory, and the design is sufficiently artistic to please when the table is in use, but unfortunately it is quite impossible to read or even distinguish objects clearly in other parts of the room, this being overlooked when the artistic effect was being aimed at.

Types of Reflectors.—With regard to the more ordinary reflectors the type chosen will clearly depend upon the work the lamp is required to do.

Bear in mind that adequate illumination of something is required. It may be that a general room illumination is sought, or, again, an even desk illumination may be the object in view, or perhaps some one object must be conspicuously lighted.

Usually the three cases call for extensive, intensive, or focussing reflectors. These may be made of an opaque material, when all the light will be thrown downwards and the upper part of the room remain in darkness, or of some material that will permit of a certain amount of light passing through it and the illumination of objects above the lamp, such as the ceiling, taking place.

When a general illumination is required, the latter type of shade should be employed, the opaque variety being installed

when all the available energy expenditure is required in some particular direction.

Extensive reflectors give a wide distribution of light, and are suitable for rooms which are low in comparison with their width and length, or for rooms employing a single central fitting.

Such reflectors provide a uniform illumination over a surface whose radius equals the height of the lamp above the working

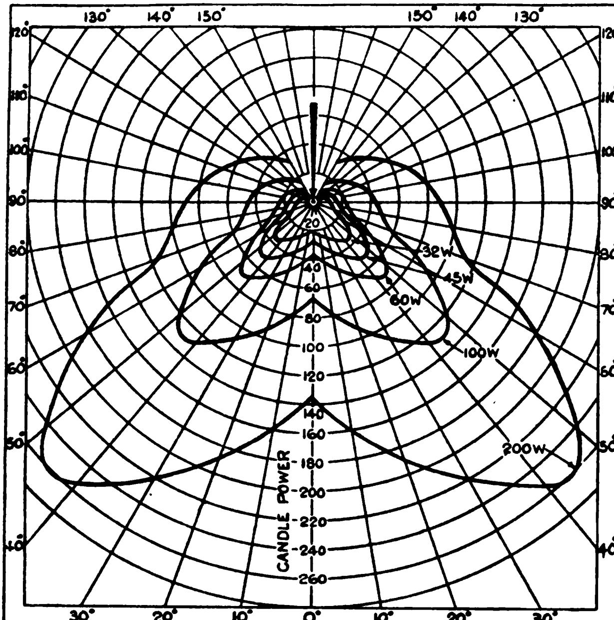

FIG. 39.—Extensive distribution.

plane, from which it is clear that if a large space is to be illuminated by several lamps, they must be fixed a distance apart equal to twice their height.

In Fig. 39 is shown the distribution to be obtained from such a reflector.

Intensive reflectors provide an intermediate illumination, as indicated in Fig. 40.

They will produce a uniform illumination over an area whose

radius is three-quarters the height of the lamp above the working plain, and consequently should be placed a distance apart equal to one and a half times their height.

Focussing reflectors throw an intense light over a small area, and are brought into use if special illumination of any particular object is required. Such a reflector will provide a uniform illumination over an area whose radius equals half the height of the lamp

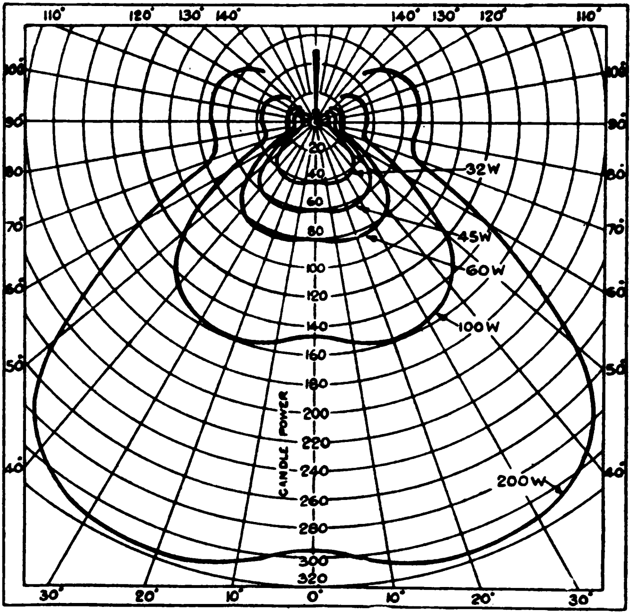

FIG. 40.—Intensive distribution.

above the working plan, and in this case the lamp should be placed a distance apart equal to their height.

The distribution from such a unit is shown in Fig. 41.

These particular types of reflector are constructed in glass and metal, and in the illustrations shown are either of holophane glass or Mazdalux metal ware.

A well-designed reflector renders the practice of hanging lamps a short distance from the ground unnecessary. The reflection is such that the lamp may be hung well out of the line of vision, and thus annoyance due to glare abolished.

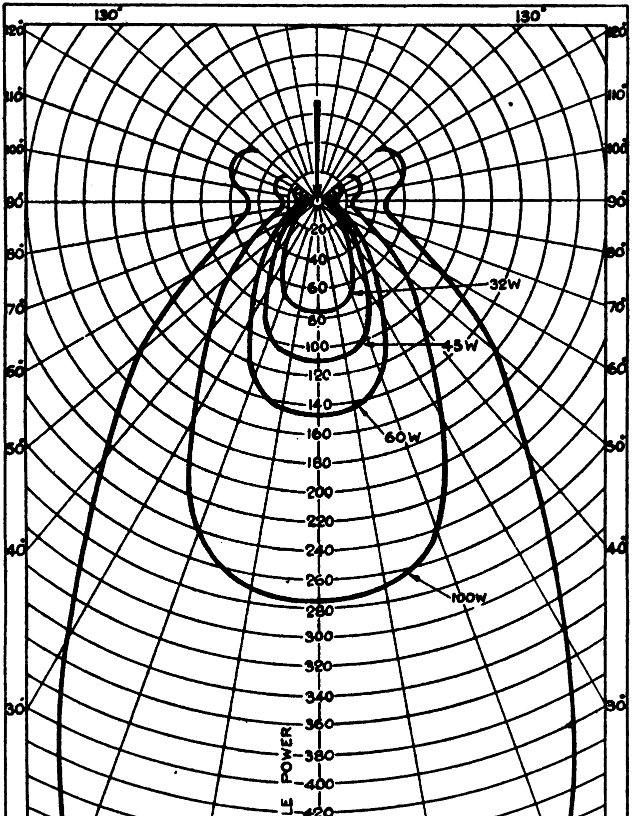

FIG. 41.—Light distribution curve with focussing reflector.

In no case should lamps be hung at a less distance above the ground than 10 feet, and, if possible, this should be increased to from 12 to 14 feet.

A further point that must not be overlooked is that the tips of all lamps should be frosted. This prevents eye-strain, resulting

FIG. 42.—Extensive reflector.

FIG. 43.—Intensive type holophane reflector.

from occasional glimpses of the unit, and makes the arrangement more nearly resemble the complete globe illustrated in Fig. 38.

That judgment must be used in installing and erecting fittings is made evident the more one sees of existing arrangements.

In the town hall of a large midland city desk fittings are used with the lamp-socket pointing upwards. The shade is such that most of the light is thrown upwards and lost, the desk receiving

FIG. 44.—Focussing type holophane reflector.

FIG. 45.—Extensive type of Veluria reflector, new scientific design of white glass.

practically none of it. Further, the lamp is in full view of all the staff, while, to crown all, the tip of the bulb is frosted.

Such a fitting, of course, was intended to be installed in an exactly opposite position, but evidently no one at hand at the time understood anything about the question.

Examples of reflectors are afforded by Figs. 42, 43, 44, 45.

Fig. 46.—Types of Mazdalux metal reflector.

Fig. 42 represents an extensive reflector, and, according to the makers, should be used for small rooms, more or less square, or for rooms where a central fixture only exists.

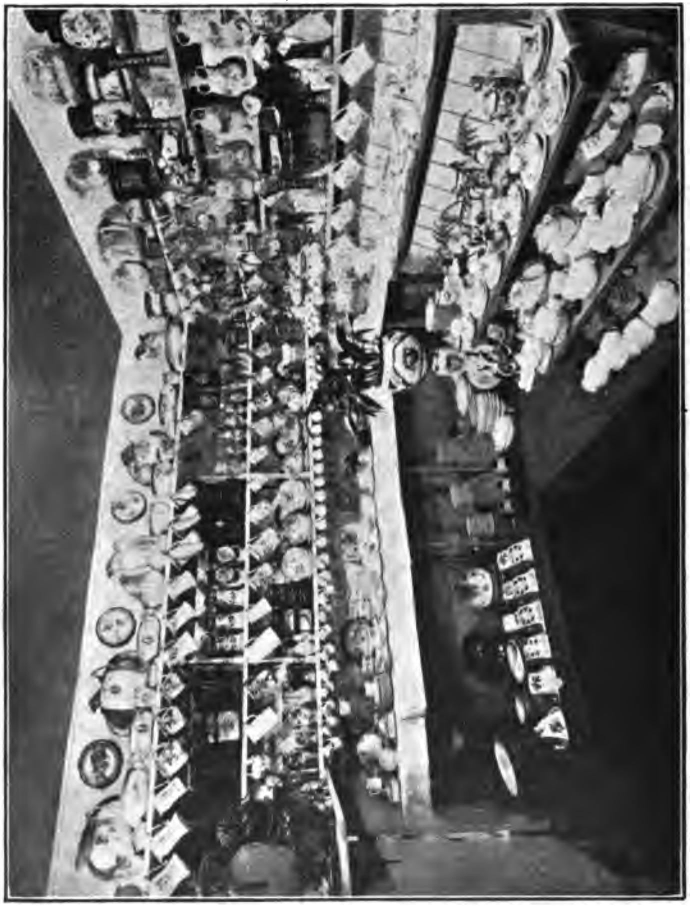

Fig. 47.—Show-room lighting.

Such reflectors may also be usefully employed in illuminating corridors and long, narrow rooms.

Fig. 43 depicts the intensive type, suitable for producing a strong illumination on the working plane in a fairly lofty room.

Such reflectors are well adapted for lighting shops, large offices, banks, etc., and, in fact, for any large interior where evenly spaced units are possible.

Fig. 48.—Composition room—Mazdalux reflectors.

Fig. 44 illustrates the focussing reflector, which type is particularly suited for the uniform illumination of high rooms, desks, and also shop windows.

In the latter case the lamps may be placed high up, well out

of the line of vision, and will produce a strong, even illumination.

A special type of reflector, known as a concentrating reflector,

FIG. 49.—Correct lighting of lace machine with angle-type Mazdalux reflector. Note the intense illumination on the lower part of the machine.

is manufactured, and is useful in all cases that require exceptional illumination, such cases frequently presenting themselves when shop-window illumination is undertaken, whilst Fig. 46 illustrates various types of metal and other reflectors.

Figs. 47–50 afford examples of lighting by the direct system, and it is seen to be quite possible to obtain an even illumination in this manner.

FIG. 50.—Lace designing room lighted with Mazdalux reflectors.

The reader would do well carefully to study these pictures, and then to compare the effect produced with that produced by unscientific installations.

Fig. 47 illustrates show-room lighting, and it is seen to be quite possible to distinguish fine detail without undue brightness existing.

In Figs. 48–50 Mazda lamps and opaque reflectors of the Mazdalux variety are employed, as all the light is required on the work.

The even illumination obtained should be specially noted, and in no way are the observer's eyes troubled by undue brightness.

The illumination required under different conditions has been indicated previously, and by the application of the illumination laws the number of units necessary may readily be determined.

CHAPTER X

LIGHTING SYSTEMS

(2) *The Indirect System*

IT is coming to be recognised more and more, as time progresses, that the present systems of lighting are, in the majority of cases, faulty ones.

The ever-present glare due to units being installed directly in the line of vision is no longer regarded as a sign of good practice.

Many are at last recognising the truth of the assertion that glare does not necessarily indicate good lighting, and that in many cases it merely means an excessive illumination in the wrong place.

The whole area in question may be rendered sufficiently bright to ensure vision being distinct and easy, without any unpleasant consequences, such as headache or eye-strain, resulting, and without doubt the indirect system affords the most satisfactory solution of the problem.

Bearing in mind the object of the system—the avoidance of brilliant light sources in the field of view—it will be obvious that the units must be so disposed as not only to be themselves invisible, but to give rise to no distressing reflections, such as in many cases take place from the surface of reflectors employed in the direct system.

The use of a large diffuse reflecting surface at once suggests itself, and such a surface is generally available in the form of a white ceiling.

No direct reflection takes place from such a surface, but the rays are scattered in all directions, and the ceiling itself appears as if it were the luminous body of a very low surface brightness. It may thus be viewed directly without any harmful effects resulting from the observation.

The question that arises is, how may the reflecting properties of such a surface be usefully utilised?

The illumination of the working plane must be even, and the

corners of the room must be as well served in this respect as the centre, while a certain amount of judicious shadow may be permitted to avoid what may be termed "flatness."

If too even an illumination is produced, the eye becomes strained somewhat in the effort to appreciate objects correctly, and the absence of shadow will be found to be wearisome.

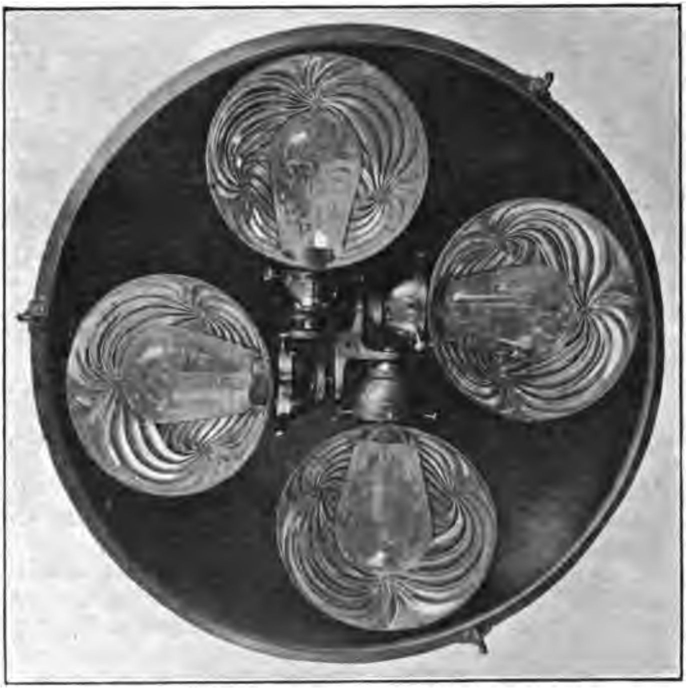

FIG. 51.—Showing arrangement of Mazda lamps and X-ray reflectors in bowl of 4-light B.T.H. "Eye-Rest" fitting.

These are, however, small points, and can be avoided, and in any case they sink into insignificance when compared with the enormous advantages to be derived from a correct appreciation of the indirect system.

Suitable Reflector.—The light must of necessity be thrown directly on to the reflecting surface, the ceiling, for example, and to do this the lamp must be supplied with an efficient reflector, fitted beneath it as shown in Fig. 51.

The reflector must be scientifically constructed, and throw the light directly on to the ceiling free from shadows, while the lamp, for best results, must be a high efficiency metal filament one. Both the lamp and reflector are contained in an opaque bowl, which can be adapted to harmonise with the decoration scheme, and thus add considerably to the artistic appearance of the room interior.

FIG. 52.—Semi-indirect fitting with Alba glass bowl.

FIG. 53.—B.T.H. "Eye-Rest" indirect fitting of moulded composition.

Indirect lighting lends itself to the production of a feeling of rest.

One becomes weary of regarding glaring bulbs, and they are to be met on every side, and in almost all public conveyances, whether train or car, and it is a positive relief to enter a room that is evenly illuminated without a single lamp being in view.

Public places such as theatres, clubs, colleges, and schools would all benefit by a revision of the existing lighting system,

without, of course, such is already the indirect one, and the patrons would experience great benefit by being relieved from the irritation caused whenever exposed light sources are in view.

Indirect lighting is particularly desirable and beneficial in drawing offices, and in works where complicated apparatus has to be studied in detail. The fact of the light coming from the ceiling, a very large reflecting area, produces a sufficient illumination in all parts.

The eyes are not strained unduly, and can thus appreciate detail.

Fig. 52 illustrates an "Eye-Rest" indirect fitting by the B T.H. company, and as it is made of moulded composition material finished matt white, it is particularly adapted for theatres, picture-halls, and other places employing plaster decorations.

Figs. 54-56 afford several striking examples of general lighting by the indirect, or what the manufacturers have happily termed the "Eye-Rest" system.

Every one at some time or other has experienced difficulty in working comfortably by light received from a single lamp suspended close to the desk, or in other words by the direct system.

The units are generally so disposed that some of the occupants of the room are bound to get in their own light. Shadows are cast on their work, and the workers' position has to be continually altered to permit of the part required receiving illumination.

This is neither good for the worker nor his employer, for one soon tires under the annoying conditions, while the other suffers from the poor quality of the work.

All this is avoided if the lighting is carried out as shown in Figs. 54-56.

Work may be carried on comfortably in all parts of the room, and the general tone lends itself to good production.

Ball-rooms are difficult places to light successfully. The dancers appreciate a soft though even illumination, and this must not vary over the floor surface. Further, an absence of glare and unshaded lights acts as an antidote to the more or less violent exercise undertaken by the occupants of the room.

The indirect system is to be recommended, and how well such a scheme may be carried out is clearly indicated in the pictures shown, the general arrangements being very similar.

To fully appreciate the beauties of pictures and statues by artificial light the lighting scheme must receive very careful attention. It is practically impossible in many galleries to make out half the pictures shown, merely because the lighting units are so badly disposed.

FIG. 54.—Church lighting—hidden Mazdalux reflectors.

They defeat their own object, and by shining in the eyes of the observer dazzle him and prevent him from seeing the picture beyond.

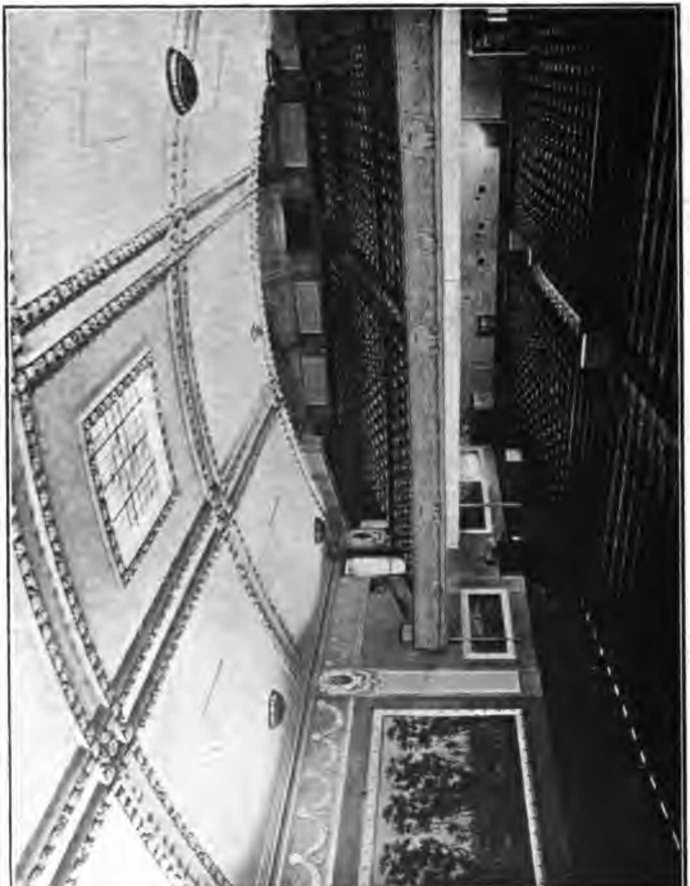

FIG. 55.—Theatre lighting—B.T.H. "Eye-Rest" System.

In theatres special attention should be paid to the disposition of the light units. The eyes of the audience are strained with gazing on the stage for protracted periods, and during the intervals they do not require to be further strained by being forced to regard

exposed light units. Screen the units if possible, should be the maxim, and if the decorations permit adopt the indirect system.

An example of theatre lighting by this system is afforded in

Fig. 56.—Temple Speech Room, Rugby School—B.T.H. "Eye-Rest" System.

Fig. 55, the way in which the decorations of the building are brought out, being not the least interesting feature of the picture.

A further example is afforded in Fig. 56, which shows the Temple Speech Room of Rugby School illuminated on the B.T.H.

" Eye-Rest " System. This will be of special interest at the present time in view of the agitation about school lighting.

Semi-Indirect Lighting.—Some people while approving of the indirect system, as far as the hiding of the units themselves goes, yet like a certain amount of direct light as well as that obtained by the diffused reflection from the ceiling, and to meet their requirements manufacturers have produced what are known as semi-indirect fittings.

In these fittings a translucent reflector is used, and some of the light is thus transmitted directly downwards. The reflector being translucent permits of the passage of light, but does not allow the light source itself to be visible, and the method partakes of both the direct and indirect without, according to its advocates, the disadvantages of either.

A semi-indirect fitting is shown in Fig. 52, and it is seen to be an object of handsome and imposing appearance.

The decorative features of a building are apt to be lost sight of if light units are in full view.

The indirect system lends itself admirably to revealing ceiling detail and architectural beauties, and is thus to be preferred in all cases where these features are strong points of the building design.

CHAPTER XI

FURTHER ILLUMINATION CALCULATIONS

CONSIDER the illumination at any point P on a horizontal plane, the source concerned being at O as indicated in Fig. 57.

The illumination varies as the square of the distance OP, and as the cosine of the angle θ, and equals

$$\frac{\mathrm{I}\cos\theta}{\mathrm{OP}^2}$$

or

$$\frac{\mathrm{I}\cos^3\theta}{\mathrm{OR}^2}$$

or

$$\frac{\mathrm{I}\cos^3\theta}{h^2}$$

I being the intensity in the direction OP, and h the vertical height of the lamp above the reference plane.

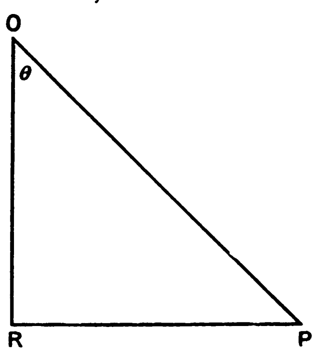

FIG. 57.

In former calculations it was assumed that the source radiated uniformly in all directions, and since when this takes place the intensity is independent of the angle θ, the curve representing the horizontal illumination on a plane will be that of the cube of the various cosines.

In practice, however, it will be found that the intensity varies with the direction of the beam, I in the above equation not being a constant, and it then becomes a matter of importance to have at hand the polar curve indicating the distribution of light in a vertical plane for the lamp in question.

From such a curve the intensity I in any direction may be

readily found, and it is then a simple matter to substitute this value in the equation given, the horizontal illumination at any particular point being thus determined.

When frequent use is made of the same polar curve it will be found to facilitate calculations enormously if illumination curves are drawn for various heights of lamp, h, above the reference plane. The values of h will be suggested by experience, and the curves once drawn will be useful in all similar installation work.

Many cases present themselves in which a knowledge of the vertical illumination rather than the horizontal illumination is required. Thus, in Fig. 57, if the vertical illumination is required at the point P, I being the intensity in the direction OP, and h the vertical height of the lamp, then the vertical illumination is equal to

$$\frac{\mathrm{I}\cos(90-\theta)}{\mathrm{OP}^2}$$

$$=\frac{\mathrm{I}\sin\theta}{\mathrm{OP}^2}$$

$$=\frac{\mathrm{I}\sin\theta}{\dfrac{\mathrm{RP}^2}{\sin^2\theta}}$$

$$=\frac{\mathrm{I}\sin^3\theta}{\mathrm{RP}^2}$$

In street and corridor lighting, and in such places as picture galleries, the vertical illumination is of as much importance as the horizontal illumination. Thus, if a person walking in the street is desirous of distinguishing the features of someone approaching him, it will be the vertical rather than the horizontal illumination that will be of interest.

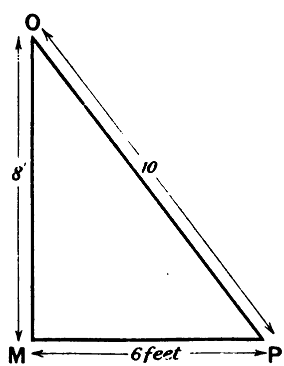

Fig. 58.

To illustrate the application of the above laws we will find the horizontal and vertical illumination at the point P shown in Fig. 58, when the distance MP is 6 feet, and the height of the lamp above the working plane 8 feet.

From the polar curve the intensity in the direction OP may be found and will be assumed to equal 60 C.P.

Then the illumination required will be given by

$$E_h = \frac{60 \times \cos^3\theta}{8^2}$$

$$= \frac{60 \times \left(\frac{8}{10}\right)^3}{8^2}$$

$$= 0{\cdot}48 \text{ foot-candle}$$

and

$$E_v = \frac{60 \times \sin^3\theta}{6^2}$$

$$= \frac{60 \times \left(\frac{6}{10}\right)^3}{6^2}$$

$$= 0{\cdot}36 \text{ foot-candle.}$$

E_h and E_v being the horizontal and vertical illumination respectively.

A study of illumination curves will reveal the fact that the illumination decreases very rapidly with the distance, and if a certain minimum illumination is specified in any particular case it becomes a simple matter to estimate the correct distances apart at which the lamps must be suspended.

Thus suppose that the minimum specified in some particular case is D foot-candles, this being the value of the illumination midway between two lamps of height "h" feet above the reference plane, and whose intensity in the given direction is I.

Then $\frac{D}{2}$ is the illumination due to either lamp, from which it follows that

$$\frac{D}{2} = \frac{I\cos^3\theta}{h^2}$$

it then being an easy matter to determine θ or I as the case may be.

If several illuminants are employed the resultant illumination may be found by the addition of the various ordinates and a resultant curve plotted. A detailed discussion of illumination curves, however, falls without the scope of the present work, and must be left for a later volume.

The illumination at any point in a room is greatly modified by the reflection that takes place from the various walls and the ceiling.

It has been mentioned previously that a white surface will

reflect some 80 per cent. of the light falling upon it, the reflection being diffused reflection, and the surface itself appearing luminous. Such reflected light will be equivalent to a distributed light of 80 per cent. of the candle-power of the original source, and it is obvious that the result will be widely different to that obtained if a black surface had been employed.

It is clear that in general cases the whole of the room surface will not possess the same reflecting powers. For instance, the floor will usually contribute nothing to the reflected light, the light falling upon it being absorbed, while dark decorations will act in the same manner.

It is, however, possible by employing suitable materials to greatly increase the resulting, or what has been termed by Mascart the total effective candle-power in the room, a careful consideration of the colour-scheme amply repaying the designer.

Imagine, for example, a room with all its surfaces of such material that 75 per cent. of the light incident upon them is reflected.

This reflected light will again fall upon the reflecting surfaces, and suffer a second reflection, the quantity now reflected, however, being 75 per cent. of 75 per cent. of the original, or 75 × 75 per cent. This amount will suffer a further reflection, 75 × 75 × 75 per cent. of the original being reflected, and so on, the total effective candle-power being increased to

$$x(1 + 0{\cdot}75 + 0{\cdot}75^2 + 0{\cdot}75^3 + \ldots) = x\frac{1}{1 - 0{\cdot}75}$$
$$= 4x$$

x being the candle-power of the source itself.

From the above it is clear that by employing material whose reflecting power is 75 per cent., the same result has been obtained as if lamps of three times the candle-power of the source had been distributed over the surfaces and no reflection at all taken place.

The various reflecting powers of different substances have been indicated in a former chapter, and it will be found instructive to work out the effective candle-power, using the same source but varying the colour-scheme of the room employed.

Thus if decorations with a coefficient of 25 per cent. are substituted for the white surfaces described above, the effective candle-power will be reduced to

$$\frac{1}{1 - 0{\cdot}25} = 1\tfrac{1}{3}$$

A value very little greater than that of the original source.

Reflector Calculations.—When use is made of any of the reflectors previously enumerated, such as extensive, intensive, or focussing holophane or Mazdalux reflectors, the following methods of calculation will be found extremely useful.

First find the area in square feet of the space that it is required to light, and multiply this by the required illumination in foot-candles, the latter being obtained from the following table.

Necessary Illumination—

Type of building.	Illumination in foot-candles.
Ball-room	3·0
Café	2·5
Church	2·0
Desk	3·0
Drawing office	5·0
Garage	2·0
Machine shop	1·5
Offices	3·0
Public hall or theatre	2·0
Reading-room	2·5
Residence	2·0
Shop	3·5
Shop window	5·0

The product thus obtained is then divided by a constant determined by experience, and influenced by the colour-scheme of the walls, etc., of the room, the resulting figure giving the watts required.

For the information of those whose experience is insufficient to furnish reliable constants several are appended.

Useful Illumination Constants—

Colour of ceiling.	Colour of walls.	Constant.
Dark	Dark	3·4
Medium	Dark	3·5
Medium	Medium	4·3
Light	Dark	4·0
Light	Medium	4·7
Light	Light	5·0

As an example of the application of the above methods, we will design the necessary installation for a café with a light ceiling and

medium-coloured walls, the length of the room being 90 feet, and its width 45 feet.

$$\text{The watts required} = \frac{90 \times 45 \times 2{\cdot}5}{4{\cdot}7}$$
$$= 2150 \text{ approximately.}$$

An even illumination, without any special concentration, is to be recommended, calling for the employment of extensive reflectors.

It will be recalled that such are to be placed a distance apart equal to twice their height above the working plane, and if this is $2\frac{1}{2}$ feet above the floor, and the lamp hung pendant 10 feet above the same, then the lamps must be suspended 15 feet apart.

Each fitting will then occupy a square of side 15 feet, and the room can be divided accordingly.

The total power required, divided by the number of points, will give the power required per point, and this

$$= \frac{2150}{18}$$
$$= 120 \text{ watts approximately.}$$

A three-light fitting, with forty watt lamps, is then to be recommended.

In many cases, two of the variable factors—height above floor, distance apart, and type of reflector—are known, in which case, the third may be readily determined from the following diagram.

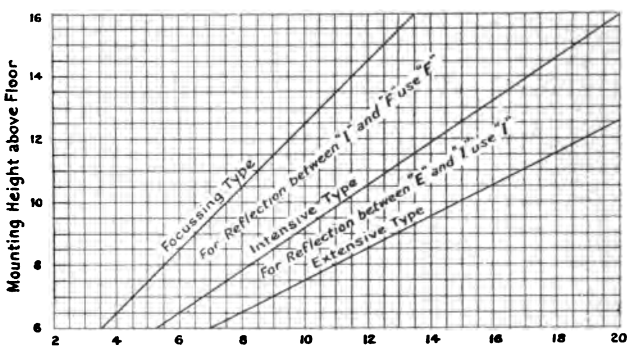

FIG. 59.

The ordinates give the height of the fitting above the floor level, and the abscissæ the average spacing distances between the

units, and these being known, the type of reflector necessary is ascertained.

For example, suppose that the units are to be installed 12 feet above the floor, and 16 feet apart. The junction of the 12 and 16 line occurs between intensive and extensive type, the former being the correct shade to employ.

Lamp Position.—When use is made of scientifically designed reflectors, apart from the ordinary shade, which is usually a light waster, and serves no useful purpose, it cannot be too strongly urged upon users that the position of the lamp is a vital one, if the correct light distribution is to be obtained.

Careless mounting of lamps inside the shades will probably destroy the whole of the effect of scientific design, so much so, that shade-makers usually provide holders to ensure correct lamp position, and such should invariably be employed.

Height of Lamp.—The height of the lamp is an important point if correct results are to be obtained, and the constants given in the tables on page 101 apply to lamps hung pendant from 10–17 feet above the floor.

Lastly, the spacing factor must be adhered to if even illumination is required, and the whole question treated as a recognised science, and not, as is too frequently the case, as a mere side-line to another business.

APPENDIX

Table of Cosines cubed

Angle.	Cosine^3.	Angle.	Cosine^3.	Angle.	Cosine^3.
0°	1·	—	—	—	—
1	0·999	27°	0·707	53°	0·218
2	0·998	28	0·688	54	0·203
3	0·997	29	0·669	55	0·189
4	0·993	30	0·649	56	0·175
5	0·988	31	0·630	57	0·161
6	0·983	32	0·610	58	0·149
7	0·978	33	0·590	59	0·137
8	0·971	34	0·570	60	0·125
9	0·963	35	0·550	61	0·114
10	0 955	36	0·529	62	0·103
11	0·945	37	0·509	63	0·0936
12	0·935	38	0·489	64	0·0841
13	0·925	39	0·469	65	0·0755
14	0·913	40	0·449	66	0·0670
15	0·901	41	0·429	67	0·0596
16	0·888	42	0·410	68	0·0526
17	0·874	43	0·391	69	0·0460
18	0·860	44	0·372	70	0·0400
19	0·845	45	0·353	71	0·0345
20	0·829	46	0·335	72	0·0295
21	0·813	47	0·317	73	0·0250
22	0·797	48	0·299	74	0·0210
23	0·780	49	0·282	75	0·0173
24	0·762	50	0·265	76	0·0142
25	0·744	51	0·249	77	0·0114
26	0·726	52	0·233	78	0·0090

INDEX

THE END

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